Technical University of Denmark

Ecolabelling of printed matter. Part II: Life cycle assessment of model sheet fed offset printed matter

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DANISH MINISTRY
OF THE ENVIRONMENT

Environmental
Protection Agency

Ecolabelling of printed matter - part II

- Life cycle assessment of model sheet fed offset printed matter

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Preface

This project has been conducted with the support of the Danish Environmental Protection Agency. It started in April 2003 and was concluded in April 2004. The project was run by the Graphics Association of Denmark, GA – the employers' federation for the Danish printing industry. The project manager was Ninna Johnsen, GA.

The project was carried out with the help of the Institute of Product Development, IPU, and the Department of Engineering and Management, IPL, Technical University of Denmark.

The purpose of the project was to analyze the Swan label criteria for printed matter from a life cycle analysis perspective and produce well founded suggestions for changes to the criteria, including recommendations concerning the synergy effect of combining environmental management and environmental product declarations. The project was also related to the development of criteria for the EU environmental label, the Flower.

The target group for the results of the project includes institutions involved in developing and defining criteria for the EU Flower label for printed matter, and Nordic institutions involved in the development, revision, approval and monitoring of the Swan label for printed matter.

The project has been delivered in two parts; the first part (part I) is the main report itself, "Ecolabelling of printed matter - part I", Environmental Project No. 1110, 2006, whereas this second part (part II) is a working report, "Ecolabelling of printed matter - part II, - "Life cycle assessment of model sheet fed offset printed matter".

This report deals with product life cycle assessment (LCA) of offset printed matter with a focus on sheet fed offset. A new generic LCA is included.

The main purpose of this LCA study is to create a basis for criteria and methodology development within eco-labelling of printed matter based on a life cycle perspective.

As well as being part of the project "Ecolabelling of printed matter" this work has been included in Henrik Fred Larsens Ph.D. study "Life cycle impact assessment with focus on chemicals" as a case study and has therefore partly been financed by the Danish Agency for Development of Trade and Industry via KEMI (Centre for chemicals in industrial production).

The members of the steering committee were:

- Søren Mørch Andersen, Danish Environmental Protection Agency
- Jesper Gruvmark, Environmental labelling secretariat
- Kerstin Sahlen, SIS Ecolabelling AB
- Kim Hansen, Phønix-Trykkeriet as
- Per K. Hansen, Stibo Graphic A/S
- Flemming Skovlund, Schultz Grafisk A/S

- Steinar Webjornsen, Media Association, Norway
- Helene Markussen, Association of Danish Daily Newspapers
- Henrik Fred Larsen, IPU, IPL,Technical University of Denmark
- Christian Poll, IPU
- Carsten Bøg, GA
- Anette Møller, GA
- Ninna Johnsen, GA

For this report Henrik Fred Larsen has done the major work and been main responsible. Morten Søes Hansen has done the modelling work in the EDIP LCV-tool and Michael Hauschild has done internal quality control of the report. Ivan Hill has done English corrections of the report and Kim Christiansen has done the critical review.

June, 2006

Summary article

New perspective on environmental impact of printed matter

Introduction

The results of a new life cycle analysis have changed the scientific basis of the criteria, which have been used up until now for the Swan ecolabel. Including chemicals to a much greater extent than in previous studies, the LCA now focuses much more on production and the use of chemicals in determining the overall environmental impact. The environmental criteria behind the Swan label for printed matter have previously been and are to some extent still currently linked to a number of earlier studies, which have all identified paper as by far the most significant environmentally damaging factor from printed matter. These studies only looked at the use of chemicals to a limited degree.

Background and purpose

Printed matter has been the most successful area for the Swan label. Currently, around 130 licences have been awarded for the product group, which outstrips any other Swan labelled types of products. The criteria document for printed matter is comprehensive, and the terms are demanding for those who wish to maintain their licences. Within the document there is an implicit balance of which phases and processes are of greater or lesser importance from an environmental perspective, and this is also based on the art of the possible in regard to current technologies and what the market can accept.

In recent years there have been lively discussions about revisions to the criteria document, as there are different views as to what weight should be placed on the many requirements the document contains, and how they should be formulated. The project was conducted largely in an attempt to illuminate these discussions. Using a complete life cycle analysis and the latest data, along with the EDIP method, meant that it was possible to update the data to form a better impression of environmental impacts generated by producing printed matter and so to make a new assessment as to whether the criteria for the Swan label actually cover all the knowledge available.

Another main reason for conducting the project was that the EU has begun the process of drawing up the initial criteria document for the Flower label in regard to printed matter. Through this project, Denmark can make a significant contribution to the scientific basis of the Flower label as well as trying to harmonise the Flower and Swan labels.

What does the life cycle analysis show?

The results of the life cycle analysis provide a picture of the varying importance of the environmental impacts generated by producing printed matter. This is the only method, which makes it possible to accord the right value to all the aspects of a product throughout its lifetime, from the extraction of raw materials through the production process, use and disposal. The EDIP method is an internationally recognised procedure for conducting a life cycle analysis, and was developed in Denmark in the 1990s, since when it has been used in a large number of both Danish and international projects.

Principal conclusions

The key conclusions of the project are summarised below:

- Including chemical data in the LCA to a greater extent than in previous studies gives a different environmental profile for printed matter than has been the case until now.
- The analyses thus could suggest that changes should be made to the existing Swan label criteria document. This applies both to the weighting of requirements for raw materials and processes in relation both to the overall production process and for the individual steps within this process.
- The results of the LCA study provide a basis for drawing up a criteria document for the EU Flower label for printed matter (sheet fed offset).
- The results of the LCA study make it possible for printing companies to work in a targeted manner with their suppliers regarding environmental aspects on a more solid scientific basis than previously, as those companies which work with standardised environmental management systems now have an improved tool for identifying their most significant environmental impacts.

A large proportion of the companies in the graphics sector have environmental management systems in place and ecolabelling licences, and allocate a lot of resources to environmental work. In the light of this data, it is even more important, both for individual companies and society as a whole that these resources are used as optimally as possible by controlling the key parameters. In the future, as a result of this project, printing companies will be able to organise their environmental work and use their resources with much more benefit for the environment than before, and also individual companies will be able to construct a more credible basis for their marketing activities.

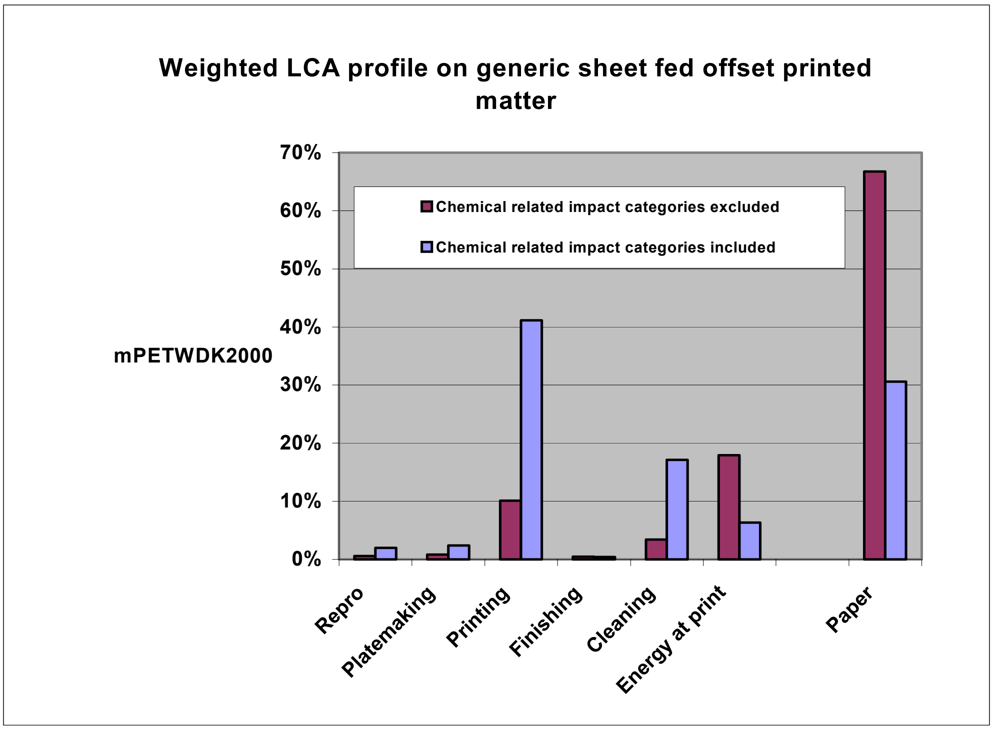
The project has resulted in two reports, one about the LCA study itself, and another, which lays out the conclusions from the LCA, study and examines the synergy effects between environmental management systems and environmental labelling.

Project results

Life cycle analysis of the production of printed matter

The aim of this study as been to identify the spread of environmental impacts throughout the entire life cycle of printed matter produced using the sheet-offset method. The functional unit taken was one tonne of printed matter.

The contribution to the environmental impact is presented for each different phase of production and using the impact categories defined by the EDIP method. Paper has been dealt with separately, because previous LCAs have shown that it is a dominant environmental factor in printed matter. However, this project has shown that if the chemicals are included on a more comprehensive basis, that printing contributes significantly more (41%) than paper (31%), see figure below. In terms of resource usage, paper is still dominant, at 48%, not least because of the energy intensive method of paper production, see report II, figure 16.



The results appear to cover the average production of printed matter both in the Nordic countries and other European countries where sheet fed offset is used. In addition to the reference scenario, seven other scenarios and various sensitivity analyses were developed in the project, with variations from the reference scenario regarding consumption, emissions, methods etc: Data used in the scenarios is, among others, based on investigations in Nordic printing companies, referring to the table 2 in the report part II. This has given rise to the following conclusions for the overall environmental impact incl. paper:

- Applying biological treatment of wastewater could reduce the environmental impact by approximately26%.
- Reducing ink use from 26.5 kg to 1.8 kg could reduce the overall environmental impact by approximately 56%. (consumptions figures from a published Swedish survey)
- Replacing the biocide benzalkonium chloride with Kathon (the active agents are two isothiazolinoner) mainly from process where water is recycled could reduce the overall environmental impact by approximately 69% (excluding wastewater treatment). The scenario is a worst case, and reference could be found in the report part II, figure 28)
- The environmental impact can be reduced with approximately 16% by using exclusivelyrecycled paper instead of exclusively virgin paper.
- The environmental impact can be reduced with approximately 26% by using entirely volatile aliphatic cleaning agents instead of entirely vegetable-based cleaning agents.

The LCA study not only provides a picture of the environmental impacts from the various phases and processes, but also, through the sensitivity analysis supports the robustness of the conclusions. One example is the surprising finding that there is only a 16% difference between using recycled or virgin paper, whereas it is clear that using the most environmentally friendly biocide makes a difference of 69%.

It should be mentioned here, however, that the LCA study, as is typical with life cycle assessments, does not include the working environment and so nor does it include any occupational health and safety consequences of, for example, substituting chemicals. These conditions therefore need to be assessed separately within the Working place assessments routines.

It was not possible to deal with some issues fully, especially because of a shortage of data. Although it is considered that including these conditions would probably not affect the overall result, some significance cannot be completely excluded.

- Other upstream chemical emissions, such as those not included in producing ink.
- Degassing of methane from paper disposed of as land fill in the cases where paper is not recycled or incinerated. The volume of methane, which ends up in the atmosphere, is not known.
- Final disposal of chemical or other waste.

Review and establishment of environmental label criteria and suppliers' environmental statements

In terms of the criteria for printed matter under the Swan label and the LCA studies up till then, the new study shows that the distribution between the environmental impacts from printed matter produced using the sheet offset method is different than previously thought.

Structure

An analysis of the criteria document shows that the current form is inconsistent in the requirements placed on the same appropriate substances throughout the processes. It is therefore proposed that the document be structured in a more rigorous way, where criteria are set in general for various substances and groups of substances and can then be adjusted (tightened or relaxed) for specific processes and materials.

Lack of knowledge

A lack of knowledge has been identified in the following areas:

- Should the focus be on the choice of inks, or on cleaner technology and emission control instead?
- How can energy be saved in the life cycle of printed matter?
- Is it possible to establish criteria for the use of transport?
- Is weight the real functional unit or should a different parameter, such as surface area, be used?

Establishing databases

For the environmental labels it would be an advantage to construct simple LCA databases, for example, for each product group or printing technique. Over time such data would make it easier to assess the consequences of such things as substitution and reduction of emissions. A common LCA data foundation would also make integration with other product-oriented schemes, such as environmental product declarations, easier.

Existing environmental product declarations

Paper Profile is an environmental product declaration, which the Nordic paper industry has developed. This scheme includes the most significant relevant emissions and requirements for energy accounting, but from an LCA perspective it can be said that energy produced internally from excess wood is not taken into account, and emissions of chemicals only include AOX. It can also be seen that the declaration scheme consists of an ISO 14020 type III (third party assessment), but as it has not been possible to fully verify it, it can be considered that it should rather be treated as a type II self-declaration. An integrated scheme on the same technical LCA basis could be used as type II, III or I scheme would be a great benefit.

Chemicals upstream
It can often be difficult to obtain data for chemicals used "upstream" in production. The reason is often because of confidentiality regarding production, but also because most suppliers to the graphics sector in Denmark are from abroad and have a different tradition for and perception of what environmental information should be given. In this study, emission data for production of pigments has been estimated with the help of a new method of estimating upstream chemical emissions developed by DTU. This has shown to have a concrete significance (17%) for the results of the life cycle study.

Supply-chain collaboration and synergy effects of incorporating environmental labels into environmental management systems

The last part of the project examines experience from Danish graphics companies' work with environmental management and the Swan label. The experience is taken from over 50 graphics companies, which have certified environmental management systems, and most of them also have a Swan licence.

The results are described systematically by firstly describing the experience of environmental management and environmental labelling, and then a number of combined effects which are typically achieved by incorporating the Swan label criteria into environmental management work and vice versa. Finally, a number of proposals are made for product-orientation of environmental management systems.

The examples of the synergy effects generated by environmental management in combination with environmental labelling selected are:

- Environmental strategy
- Environmental conditions, significant impacts and areas of initiative
- Evaluation of raw materials - waste
- Evaluating the production equipment
- Consumption of raw materials
- Advising customers
- Audit and monitoring

Despite a certain divergence between significant environmental conditions pointed out in environmental management systems in general and the significant environmental conditions contained in the Swan label criteria document, it can be said that an important synergy can be achieved to the benefit of the environment if the criteria document is used as the basis for the environmental management system in the areas mentioned above. It is considered that carrying out this LCA study will further strengthen this.

Throughout the course of the project the results have been incorporated in the Swedish Standards Institute's work for the European Commission with the aim of producing criteria for a European environmental label for printed matter. In general, the use of environmental management systems in graphics companies in Europe has spread to a certain degree, and it can be stated that the criteria document for the environmental Flower label, based on experience gathered from Denmark, would be able to provide a supportive and positive influence on the environment in terms of graphics production in Europe. This work would allow Denmark to contribute to a positive development on markets much larger than the Nordic one.

Other sources

www.miljonet.org
www.ecolabel.dk
www.paperprofile.com
www.lca-center.dk
www.ga.dk

Sammenfattende artikel

Nyt syn på miljøbelastningen fra tryksager

Manchet
Resultaterne fra et nyt livscyklusstudie ændrer på den viden, de eksisterende kriterier for Svanemærkning af tryksager hidtil har lænet sig op ad. Ved at inddrage kemikalier i LCA studiet i langt højere grad end i tidligere studier, rettes der nu i højere grad fokus mod produktionen og mod anvendelsen af kemikalier, når den samlede miljøbelastning skal gøres op. Miljømærkekriterierne under Svanen for tryksager har tidligere og i deres nuværende form i nogen grad knyttet sig til en række ældre studier, der alle har peget på papir som den altoverskyggende miljøbelastende faktor ved tryksager. Disse studier har kun i meget begrænset omfang indregnet kemikalier.

Baggrund og formål

Miljømærket Svanens største succes er tryksagerne. Der findes i dag ca. 130 licenser for denne produktgruppe, hvilket langt overgår alle andre produktgrupper under Svanen. Kriterierne for tryksager er et omfattende dokument, som det er krævende at arbejde med, og som stiller store krav til licensansøgeren. I dokumentet ligger implicit en afvejning af, hvilke faser og processer der er mere eller mindre væsentlige ud fra et miljømæssigt synspunkt, men også en afvejning baseret på det muliges kunst i forhold til hvad den aktuelle teknologi og markedet kan følge med til.

Der har i de senere år været livlige diskussioner omkring revisionerne af kriteriedokumentet, idet der er forskellige opfattelser af, hvordan vægten og formuleringen skal være for de mange krav, der ligger i dokumentet. Disse diskussioner er en væsentlig årsag til, at projektet blev igangsat. Ved at gennemføre en fuld livscyklusvurdering med nyeste data og UMIP-metoden blev det muligt at få et opdateret indtryk af miljøbelastningerne ved produktion af tryksager, og dermed også et oplæg til en fornyet vurdering af, om vægtningerne i Svane-kriterierne er dækkende for den tilgængelige viden.

En anden væsentlig årsag, til at projektet blev igangsat, er at EU har igangsat udvikling af det første kriteriedokument for Blomsten for tryksager. Ved at gennemføre nærværende projektet kan Danmark give et væsentligt bidrag til det faglige grundlag for Blomsten samt til at harmonisere Blomst- og Svanekriterierne.

Hvad viser en livscyklusvurdering?
Resultaterne af en livscyklusvurdering kan give et billede af, hvor miljøbelastningen af et produkt er mere eller mindre betydende. Metoden er den eneste, der giver mulighed for at se og vurdere denne afvejning af belastningen i hele produktets livsforløb fra råstofudvinding over produktion, forbrug og bortskaffelse. UMIP-metoden er en internationalt anerkendt metode til livscyklusvurdering udviklet i Danmark i 1990'erne, som har været benyttet i dette og en lang række andre danske og internationale projekter.

Hovedkonklusioner

Projektets væsentligste konklusioner kan udtrykkes i følgende:

- Inddragelse af data for kemikalier i LCA i højere grad end i tidligere undersøgelser giver en anderledes miljøprofil for tryksagen end hidtil
- De gennemførte analyser lægger derfor op til ændringer i det kommende kriteriedokument for Svanen. Dette gælder både for vægtningen af krav til råvarer og processer i relation til den samlede produktionsproces og inden for de enkelte afgrænsede procesled
- Resultaterne fra LCA-studiet giver et fundament for etablering af et kriteriedokument for EU's miljømærke, Blomsten, for tryksager (arkoffset)
- Resultaterne fra LCA-studiet gør det muligt for grafiske virksomheder at målrette deres leverandørsamarbejde på miljøområdet på et bedre vidensgrundlag end tidligere, ligesom de virksomheder, der arbejder med standardiserede miljøledelsessystemer, har fået et forbedret værktøj til at udpege de væsentligste miljøpåvirkninger

I den grafiske branche produceres en meget stor del af tryksagerne på virksomheder, der har miljøledelsessystemer og miljømærkelicenser, og der bruges mange ressourcer på miljøarbejde i disse virksomheder. I lyset af disse kendsgerninger bliver det endnu mere vigtigt både for den enkelte virksomhed og samfundet som helhed, at disse ressourcer anvendes så optimalt som muligt ved at styre de væsentlige miljøparametre. Med resultaterne fra dette projekt vil de grafiske virksomheder fremover kunne tilrettelægge deres miljøarbejde og anvende deres ressourcer til langt større gavn for miljøet end tidligere, ligesom den enkelte virksomhed vil få et mere udbygget troværdighedsgrundlag at foretage sin miljømarkedsføring på.

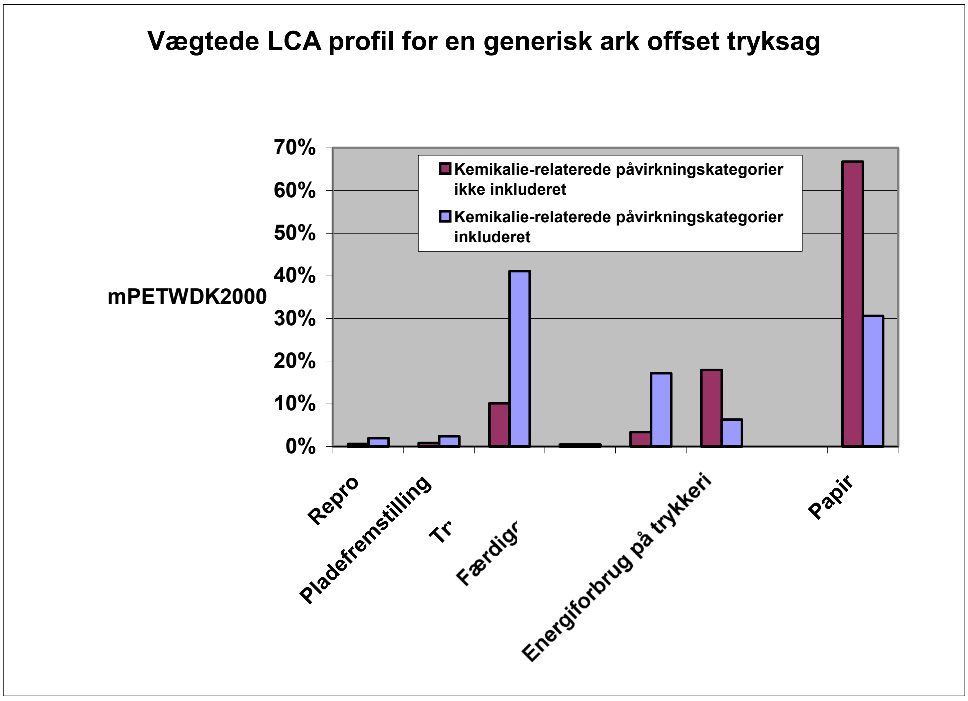
Projektet er afrapporteret i to rapporter: En rapport der beskriver selve LCA-studiet, og en rapport der dels beskriver konklusionerne for LCA-studiet og dels synergieffekter mellem miljøledelse og miljømærkning.

Projektresultater

Livscyklusvurdering af produktion af tryksager

Formålet med denne undersøgelse har været at identificere fordelingen af miljøpåvirkninger fra hele livscyklussen af en gennemsnitlig tryksag produceret ved arkoffset metoden. Den funktionelle enhed har været 1 ton tryksag.

Bidraget til miljøpåvirkningerne er præsenteret opdelt på de forskellige faser i fremstillingen af tryksagen og på UMIP-metodens påvirkningskategorier. Papir er skilt ud, fordi tidligere LCA-studier har vist, at papir er den dominerende miljøfaktor for tryksager. Men dette projekt har vist, at hvis man inddrager kemikalier mere fyldestgørende, så bliver selve trykkeprocessen, inklusiv trykfarverne mere betydende (41%) end papir (31%), se figur nedenfor. Ud fra en ressourcebetragtning er papir stadig dominerende med 48%, især pga. det høje energiforbrug ved papirproduktion, se figur 16 i rapportens del II.



Resultaterne vurderes at dække såvel en gennemsnitlig nordisk som europæisk tryksagsproduktion ved arkoffset-metoden. Ud over referencescenariet blev der i projektet udviklet syv andre scenarier og diverse følsomhedsanalyser, hvor der i forhold til referencescenariet blev varieret på forbrug, emissioner, metoder osv.; data anvendt i scenarierne er bl.a. baseret på undersøgelser på nordiske offset-trykkerier, som fremgår af tabel 2 i projektets Del II rapport. Dette gav anledning til følgende konklusioner for den samlede miljøpåvirkning inkl. papir:

- Ved at inddrage spildevandsrensning med biologisk rensning kunne miljøpåvirkningen reduceres med ca. 26%
- Ved at reducere trykfarveforbruget fra 26,5 kg til 1,8 kg kunne miljøpåvirkningen reduceres med ca. 56% (forbrugstal fra publiceret svensk undersøgelse).
- Ved at substituere biocidet benzalkoniumklorid med biocidet Kathon (aktivstofferne er to isothiazolinoner), primært i de processer, hvor der recirkuleres vand, kunne miljøpåvirkningen reduceres med ca. 69% (uden spildevandsrensning)
- Miljøpåvirkningen reduceres med ca. 16%, hvis der udelukkende anvendes genbrugspapir i stedet for udelukkende jomfrueligt papir
- Miljøpåvirkningen reduceres med ca. 26%, hvis der udelukkende avendes afvaskere baseret på vegetabilsk olier i stedet for udelukkende flygtige alifatiske afvaskere

LCA-studiet giver altså ikke blot et billede af fordelingen af miljøpåvirkningerne fra de forskellige faser og processer, men også – via følsomhedsanalysen – en indsigt i robustheden af konklusionerne. Fx kan det overraske, at der ikke er mere end 16% forskel imellem genbrugspapir og jomfrueligt papir, hvorimod det bliver tydeligt, hvor væsentligt det er at vælge det mindst miljøbelastende biocid, da forskellen her er 69%.

Det skal dog her bemærkes at LCA-studiet, som typisk for livscyklusvurderinger, ikke omfatter arbejdsmiljø og derfor heller ikke eventuelle arbejdsmiljømæssige konsekvenser af f.eks. kemikaliesubstitution. Disse forhold må derfor vurderes separat.

Visse problemstillinger har det ikke været muligt at behandle fuldt ud på grund af især datamangel. Selvom det umiddelbart vurderes, at inddragelse af disse forhold sandsynligvis ikke vil ændre det overordnede resultat, kan en betydning ikke helt udelukkes:

- Andre opstrømskemikalieemissioner, fx andre end de inkluderede til produktion af trykfarver
- Afgasning af metan fra deponering af papir i det omfang, papiret ikke bliver genbrugt eller forbrændt. Mængden af metan, der ender i atmosfæren, kendes ikke
- Endelig bortskaffelse af kemikalieaffald

Revision og etablering af miljømærkekriterier samt leverandørers miljøvaredeklarationer

I forhold til kriterierne for tryksager under Svanen og de hidtidige LCA-studier viser det nye studie, at fordelingen imellem miljøpåvirkningerne fra tryksager produceret ved brug af arkoffset-metoden er anderledes end hidtil antaget.

- Struktur
En analyse af kriteriedokumentet viser, at den nuværende form ikke konsekvent stiller krav til samme relevante stoffer processerne igennem. Derfor foreslås en ændret og mere stringent struktur for dokumentet, hvor kriterier sættes generelt for forskellige stoffer og stofgrupper og derefter kan afviges (strammes eller lempes) for specifikke processer eller materialer.

- Manglende viden
Manglende viden er identificeret inden for følgende områder:

- Skal der fokuseres på valg af trykfarvetyper, eller skal der i stedet fokuseres på renere teknologi og emissionskontrol?
- Hvor kan der spares energi i livscyklus for en tryksag?
- Er det muligt at sætte kriterier op for transportydelser?
- Er vægt den rette funktionelle enhed, eller bør det i stedet være parametre som f.eks. trykt overfladeareal?

- Etablering af databaser
For miljømærkeordningerne vil der være fordele ved at opbygge simple LCA-databaser fx for hver produktgruppe eller trykketeknik. Sådanne data vil med tiden gøre det lettere at vurdere konsekvenser af fx substitution og reduktion i emissioner. Med et fælles LCA-datagrundlag vil også integration med andre produktorienterede ordninger fx miljøvaredeklarationer blive nemmere.

- Eksisterende miljøvaredeklarationer
Paper Profile er en miljøvaredeklaration, som papirbranchen i Norden har udviklet. Denne ordning omfatter de væsentligste relevante emissioner og krav om energiopgørelse, men set i et LCA-perspektiv kan det konstateres, at denne ordning ikke medregner energi, produceret internt fra overskudstræ, og hvad angår emission af kemikalier kun medtager AOX. Yderligere ses det, at denne deklarationsordning fremstår som en ISO 14020 type III-ordning (tredjepartsvurderet), men da dette ikke fuldt har kunnet verificeres, må det antages, at denne nærmere må betragtes som en type II-selvdeklarering. En integreret ordning, som på samme faglige LCA-grundlag kunne bruges som en type II-, III- og I-ordning ville være en stor fordel.

- Kemikalier opstrøms

Det kan ofte være vanskeligt at få data for kemikalier brugt ”opstrøms” i produktionen. Årsagerne til dette begrundes ofte med produktionshemmeligheder, ligesom de fleste af leverandører til den grafiske branche i Danmark er udenlandske og har en anden tradition for og opfattelse af, hvad der bør gives af miljøoplysninger. I dette studie er udledningsdata ved produktionen af pigmenter derfor estimeret ved hjælp af en ny metode til estimering af opstrømskemikalieemissioner udviklet på DTU. Dette har konkret vist sig at have væsentlig betydning (17%) for resultaterne af livscyklusstudiet.

Leverandørkædesamarbejde og synergieffekter ved inddragelse af miljømærker i miljøledelsessystemer

I projektets sidste del er erfaringer fra danske grafiske virksomheders arbejde med miljøledelse og Svanen gennemgået. Erfaringerne tager udgangspunkt i de mere end 50 grafiske virksomheder, der har et certificeret miljøledelsessystem og samtidig for de fleste vedkommende også en licens til svanemærkning.

Resultaterne er beskrevet systematisk ved først at beskrive erfaringer for henholdsvis miljøledelse og miljømærkning, derefter en række sammenvirkende effekter, der typisk er opnået ved inddragelse af svanemærkekriteriet i miljøledelsesarbejdet og vice versa, og afslutningsvis gives en række forslag til produktorientering af miljøledelsessystemer.

De udvalgte eksempler på synergieffekter miljøledelse og miljømærker imellem, der beskrives er:

- Miljøstrategi
- Miljøforhold, væsentlige påvirkninger og indsatsområder
- Vurdering af råvarer – spild
- Vurdering af produktionsudstyr
- Forbrug af råvarer
- Rådgivning af kunder
- Audit og kontrol

På trods af en vis divergens mellem væsentlige miljøforhold udpeget i miljøledelsessystemer i almindelighed og væsentlige miljøforhold, som fremgår af kriteriedokumentet for Svanen, kan det konstateres, at der opnås en væsentlig synergi til gavn for miljøet, hvis man anvender kriteriedokumentet som udgangspunkt for miljøledelsessystemet på ovennævnte områder. Det vurderes, at det gennemførte LCA-studie vil styrke dette yderligere.

Resultaterne har løbende i projektprocessen været inddraget i Det Svenske Standardiseringsinstituts arbejde for Europa Kommissionen med henblik på at udarbejde et kriterium for et Europæisk miljømærke for tryksager. Generelt har anvendelsen af miljøledelsessystemer i grafiske virksomheder i Europa en vis udbredelse, hvorfor det må antages, at et kriteriedokument for miljømærket Blomsten med baggrund i erfaringerne fra Danmark vil kunne få en understøttende positiv virkning på miljøet i forbindelse med grafisk produktion i Europa. Danmark vil med dette arbejde kunne medvirke til en positiv udvikling på markeder, der er langt større end de nordiske.

Andre kilder

www.miljonet.org
www.ecolabel.dk
www.paperprofile.com
www.lca-center.dk
www.ga.dk

Summary and conclusions

Studies covering the life cycle from cradle to grave of printed matter products have been carried out over the last ten years. Though the number of studies is limited, 4-5 of them include offset printed matter. All these life cycle assessments (LCAs) focus on energy consumption and energy related impact categories, whereas chemical related impact categories covering ecotoxicity and human toxicity are only included to a limited degree or not at all. Results of all these existing LCA's point to paper as the dominating contributor to the potential environmental impact from the life-cycle of offset printed matter. In only one of the existing studies is sheet fed offset produced printed matter included as a separate entity, and in that particular case the chemical related impact categories are not included at all.

In this report we include the chemical related impact categories to a higher degree and focus on an LCA of generic sheet fed offset printed matter produced at a model sheet fed printing company.

The LCA methodology chosen in this study is the EDIP method. This methodology with its relatively simple key property based impact assessment part seems feasible for the LCA approach relevant for use in ecolabelling of products associated with many chemical emissions.

Goal and scope definition

The goal of the study is to identify the distribution of potential environmental impacts and consumption of resources during the life cycle of generic printed matter produced on a model sheet feed offset printing company in Europe. The results are to be used for developing ecolabelling criteria.

Main activities at all stages in the life cycle are covered to the degree that readily available data has made possible and average/typical data have been used, i.e. not from a specific printing company with a functional unit defined in details. However the stage of use for which only transport may be important is excluded but assessed on basis of existing studies.

There is a special focus on the production stage but upstream emissions assessed to be of possible significance are included (e.g. estimated emissions from pigment production) or dealt with in the sensitivity analysis. The data are assessed as being suitable for developing ecolabelling criteria from an LCA approach, especially if combined with sensitivity analyses.

The functional unit is 1 ton of sheet feed offset produced printed matter, i.e. printed communication covering books, pamphlets etc.

The impact assessment categories used includes global warming, ozone depletion, acidification, nutrient enrichment, photochemical ozone formation, chronic human toxicity via water and soil, chronic ecotoxicity in water and soil, acute human toxicity via air, acute ecotoxicity in water, hazardous waste, nuclear waste, slag and ashes, and bulk waste. Resource consumption is also included.

As the time scope for the production stage 1990 – 2002 has been chosen and the technological scope is mainly modern technology (not state-of-the-art) used at least in Northern Europe.

Marginal approaches are used for production of electricity (natural gas) and paper production (virgin fibres) as the main approach in the reference scenario. In all other cases an average approach is used.

Waste water treatment is not included in the reference scenario, making this scenario also relevant for Southern and Eastern Europe. However, a special scenario with waste water treatment is included and can be considered as being relevant for Northern Europe, especially Sweden and Denmark.

In the reference scenario the avoided energy consumption and avoided emissions from incineration and recycling of paper are either not allocated to the functional unit (designated paper gross) or allocated to the functional unit (designated paper net). For consumption of aluminium, it is assumed that recycled aluminium is used and the extra energy used to produce virgin aluminium to replace the loss during the recycling process is allocated to the functional unit. For both paper and aluminium the effect of changing the allocation used is discussed or investigated by the use of sensitivity analysis.

As this study is going to be used for ecolabelling, the main focus is on the production stage, i.e. page production (repro), plate making, printing, finishing and cleaning. The raw materials included in the production stage cover the dominant types typically used in ‘traditional’ sheet feed offset, i.e. film, film developer, fixer, biocides, plates, plate developer, gumming solution, paper, alcohol (isopropyl alcohol, IPA), printing ink, fountain solution, lacquer (varnishes), glue and cleaning agents. The composition of these raw materials is as far as possible based on known typical recipes, but due to lack of data and relevance simplifications and assumptions about the components have been made.

Due to the focus on the production stage and lack of data on consumptions and emissions, the material and disposal stages are only taken into account as far as they are covered by the unit processes included. This means that emissions of specific substances are typically not included. Ink, paper and energy production are exceptions for which emissions of specific substances are included at least to some degree.

The consumption of raw materials at the model printing company is mainly based on average values for 10 – 70 Swedish and Danish offset printing industries. The range in the consumption of the most important raw materials is typically well below (e.g. factor of 2 for paper) or just above (e.g. factor of 15 for ink) a factor of about 10.

The emissions to water and air at the model printing company are also mainly based on Swedish and Danish investigations. Non-volatile substances (e.g. biocides) appearing in rinse water and fountain solutions are assumed to be 100% emitted to water. 70 – 95% of volatile solvents are assumed to be emitted to air and in this case only 0.1% or 1% (depending on the type) is emitted to water with IPA as an exception, i.e. 14% emitted to water. The rest of the used solvents are disposed of as chemical waste.

Besides the reference scenario for which the conditions are described above, seven special scenarios have been drawn up. These scenarios are based on the reference scenario but are different in a few parameters. Scenario 1 makes use of an average electricity scenario in order to be able to compare with an existing LCA study. Scenario 2 assumes a saturated paper market with the purpose of being able to see the consequences of the use of recycled paper at the model printing company. Both scenarios 3 and 4 cover a sensitivity analysis making use of the observed ranges in the paper and ink consumption respectively. In scenario 5 waste water treatment is included and in scenario 6 the effect of substitution among biocides is shown. Finally scenario 7 deals with the situation where no waste water at all is emitted from the model printing company.

Methodology

The impact assessment used here comprises classification, characterisation, normalisation and weighting. During classification all the emissions mapped in the inventory and related to the functional unit are grouped substance wise and assigned to the relevant impact categories. Later in the characterisation step these values are multiplied by the corresponding characterisation factor (one for each substance emission) and then all these contributions are aggregated into one value called category indicator result within each impact category. Then during normalisation these category indicator results are normalised by dividing each one by the corresponding yearly total impact per world citizen (or country citizen depending on category) leading to a normalised value for each impact category expressed in units of person equivalents. Finally each normalised value is multiplied by a weighting factor which in the EDIP method is determined by political reduction targets (the higher the reduction the higher the weighting factor). For resource consumption something similar is done by dividing the consumption into groups of pure raw material (e.g. copper), normalising by dividing with yearly resource consumption per world citizen and finally weighting by factors based on the reciprocal of the supply horizon so that the weighted result is expressed in units of person-reserves.

For the chemical related impact categories (i.e. chronic human toxicity, chronic ecotoxicity, acute human toxicity, acute ecotoxicity) the chronic ones are aggregated into one category called 'persistent toxicity' during the normalisation step leading to only three chemical related impact categories after normalisation. No aggregation has been done for the other impact categories (i.e. the energy related ones) during normalisation. The weighting step makes it possible to aggregate contributions from each impact category into one aggregated value for potential environmental impact expressed in targeted person equivalents (PET) for one functional unit. In the same way the total resource consumption can be aggregated into one value expressed in person-reserves per functional unit.

The chemical related impact categories differ from the energy related ones because a very large number of chemical emissions may contribute to potential toxicological impact. Substances contributing to the energy related impact categories (e.g. global warming, nutrient enrichment and acidification) are limited in number and well-defined, and characterisation factors are already available. However for the chemical related impact categories only characterisation factors for a limited number of contributing emissions are available today.

In this study 33% and 26% of the number of mapped emissions to air are covered by characterisation factors for human toxicity and ecotoxicity respectively. If expressed in quantity (kg) 48% is covered by characterisation factors for human toxicity and 64% for ecotoxicity if the known main non-contributing emissions for ecotoxicity (such as SO_2 and calcium) are excluded. The figures for emissions to water are 25% and 37% for the number of emissions covered by characterisation factors for human toxicity and ecotoxicity respectively and if expressed as quantity the figures are 48% for human toxicity and 53% for ecotoxicity when main non-substance specific (e.g. suspended solids and COD) and most probably non-contributing emissions are excluded. However the major part of the specific substances emitted to water for which no characterisation factors exist includes inorganic salts, polymers and acids/bases of the type that are generally assessed to be low in toxicity. It has not proved possible to include a few known substances belonging to groups such as siccatives and softeners which might contribute significantly to the chemical related impact categories. New characterisation factors on ecotoxicity for 11 substances covering pigments, biocides and others have been calculated as part of this study.

Results

The total category indicator results for one functional unit covering the reference scenario are shown in Table 17 (Section 3.3). The main results of analysing the background for these figures show that the energy related impact categories are dominated by contributions from energy production (material stage) especially for paper production but also from energy consumption at the model printing company. For the chemical related impact categories the main contributions come from emissions of solvents used during cleaning and printing at the model printing company (production stage) but also emission during pigment production and emission from energy production (e.g. heavy metals), which both belong to the material stage, do contribute significantly. For resources the major consumptions are of water (used mainly for paper production), of the group of energy carriers comprising natural gas, oil and wood, and of kaolin for production of paper.

By normalising the category indicator results a normalised LCA profile appears (see Figure 2 in Section 3.3.1.1). The dominant impact categories are ecotoxicity (i.e. acute ecotoxicity) and global warming followed by hazardous waste and persistent toxicity. Ecotoxicity accounts for about 400 mPE (milli-person-equivalents) and the main contributing activities are printing (240 mPE) and paper production (80 mPE). For global warming the value is about 240 mPE dominated by contributions from paper production (170 mPE) and energy consumption at the model printing company (60 mPE). Hazardous waste accounts for about 159 mPE and is almost fully dominated by paper production (154 mPE). Persistent toxicity accounts for 142 mPE dominated by cleaning (66 mPE), printing (43 mPE) and paper production (24 mPE). If negative contributions from paper incineration and paper recycling (due to avoidance of burning fossil fuels and avoidance of producing virgin paper) are allocated to paper in the profile (i.e. paper net is used) the contribution from paper to, for example, global warming is reduced from 71% to 43%.

The normalised profile for the non-renewable resources is shown in Figure 4 in Section 3.3.1.2. This profile is heavily dominated by consumption of kaolin (111000 mPE) during paper production (used as filler). However kaolin can easily be substituted by talc and/or chalk leading to a reduction by several orders of magnitude in importance of the filler. The second highest normalised resource consumption is consumption of natural gas, accounting for 1570 mPE dominated by consumption during paper production (967 mPE) and consumption at the model printing company (452 mPE).

The main effects of weighting the normalised profile are that the impact category on ecotoxicity becomes even more dominant than after normalisation and that persistent toxicity is now second most important and global warming is now only the third most important, see Figure 6 in Section 3.3.2.1. By weighting we have the opportunity to aggregate all the environmental impact category results into one common impact score. If we do that and further use the net value for paper, we can express the contribution of the different activities to the total aggregated weighted potential impact (hereafter called “aggregated impact”) in terms percent contribution. The result is that the highest contribution to this weighted profile (see Figure 9 in Section 3.3.2.1) comes from printing (41%) followed by paper net (31%), cleaning (17%), energy consumption at the model printing company (6%), plate making (2%), repro (2%) and finally finishing (0.4%).

After weighting of the resource profile kaolin is still dominant but especially natural gas, oil and uranium have increased importance (see Figure 11 in Section 3.3.2.2). If we exclude kaolin, as we did for normalisation, and use the net value for paper, and further aggregate all weighted resource consumptions and express the result in percentage of the total, we arrive at the profile shown in Figure 16 (Section 3.3.2.2.). In this case the highest share of resource consumption comes from paper net (48%) followed by energy consumption at the model printing company (33%), repro (6%), finishing (4%), printing (4%), cleaning (3%) and plate making (2%).

The result of the comparison between scenario 1 (average electricity scenario) and a previous LCA study of offset printed matter, i.e. a newspaper (cold-set) and a commercial (heat-set) shows that scenario 1 is pretty much at the same level for the energy related impact categories. However the dominant position of the chemical related impact categories in scenario 1 is not at all reflected in the previousstudies due to the fact that only one emission (IPA) is included.

The effect of using recycled paper exclusively (scenario 2) as compared to the use of virgin paper exclusively (reference scenario) is a reduction in the aggregated impact of about 16%.

If the waste paper amount (i.e. paper spillage in production) at the model printing company is reduced from 32% to 3.3% (scenario 3) the reduction in the aggregated impact is about 11%.

Reducing the ink consumption from 26.5 kg/functional unit (fu) to 1.8 kg/fu at the model printing company (scenario 4) leads to a reduction in the aggregated impact of about 56%.

Introducing the use of a waste water treatment plant (WWTP) (scenario 5) for waste water emitted from the model printing company results in a reduction in the aggregated impact of about 26%.

The effect of substituting chemicals at the model printing company is illustrated by substitution among biocides for preservation of rinse water (Scenario 6). Substitution of benzalkonium chloride with Kathon results in a reduction in the aggregated impact of about 21% (WWTP included) or about 69% (WWTP not included).

If no waste water at all is emitted from the model printing company (scenario 7) the reductions in the aggregated impacts are about 30% if compared to the reference scenario with no WWTP or 5% if compared to scenario 5 with WWTP.

Interpretation

In order to investigate the robustness of the reference scenario and the effect on the LCA profile of varying the consumption and emissions at the model printing company within observed ranges (relevant for ecolabelling) sensitivity analyses have been carried out.

The effect of using drafted new normalisation references and weighting factors covering the 15 current EU member states instead of the Danish ones as used in the reference scenario is investigated. The result is that changing to EU-15 values does not change the overall LCA-profile for the reference scenario significantly. So in this regard the weighted reference scenario used in this study is considered as robust and valid on a European scale.

For paper the use of other allocation principles (“cut-off” and quasi-co-product) than the paper gross and paper net used in this study is discussed. It is concluded that due to the dominant use of virgin paper within sheet fed offset the choice of paper net is most relevant for the reference scenario in our case.

In the previous LCA studies of offset printed matter which all only include the chemical related impact categories to a limited degree or not at all the importance of paper in the LCA profiles is at the level of 70 – 80%. In this study paper net accounts for only 31% but if the chemical related impact categories are excluded this figure is raised to 67% which is at the same level as in the previous studies.

One of the known emissions of toxic substances from paper production that it has not been possible to include in this study is AOX (chlorinated organic substances emitted to water). A very roughly estimate indicates that this emission might account for about 3% of the aggregated impact. However it is assessed that taking other emissions from other activities into account that have also not been possible to include (e.g. emission of siccatives at the printing process) the AOX emission will probably not change the overall LCA profile. However this assessment is of course based on existing available knowledge within the scope of this study.

The inclusion of a European paper disposal scenario is investigated. The main issue here is the land filling of paper waste leading to emission of methane that contributes to global warming. However consideration about a higher recycling rate (than average) for high grade graphic paper combined with considerations about oxidation and utilisation of methane leads to the assessment that inclusion of land filling of paper waste does probably not change the LCA profile for sheet fed offset printed matter substantially and that the reference scenario therefore is sufficiently robust to represent the average European situation regarding paper disposal.

The printing process accounts for 41% (production of printing ink included) of the aggregated impact in the reference scenario. Such a high importance is not shown at all in previous LCA studies of offset printed matter which is mainly due to a limited or absence of inclusion of the chemical related impact categories.

The production of printing ink accounts for 17% of the aggregated impact in the reference scenario, mainly due to estimated emissions during pigment production. Even though these estimations (not done as part of this study) are based on risk assessment tools they are assessed to be non-conservative. A short critical review of the estimations has revealed errors that after corrections lead to an increase in the importance of production of printing ink from 17% to 20%. This may point to a higher importance of pigment production.

The very high importance of printing ink consumption is illustrated by estimating the importance for the aggregated impact on basis of the observed range at printing industries, i.e. 1.8 kg/fu – 26.5 kg/fu. The result shows an importance of 23% at the lower range value and 74% for the upper range value. If it is assumed that emissions of printing ink residues at the model printing company are not proportional to the consumption but constant (probably most realistic) the corresponding importance becomes 34% and 63% respectively.

Looking at the emissions of printing ink at the model printing company separately and assuming a variation of a factor 10 (0.3% - 3%) for the 1% emission used in the reference scenario leads to a variation in the importance of 6% for the lower range value and 39% for the upper range value. Again this shows the high importance of printing ink and high sensitivity in the reference scenario to variation in this parameter. Anyway it is assessed that an emission of 1% of the consumption represents emission of ink residues for a generic sheet fed offset LCA fairly accurately.

The contribution from emission of IPA to the aggregated impact in the reference scenario is 6%. Variation in the emitted amount according to the observed range of consumption at the printing companies (0.0785 kg/fu – 10.4 kg/fu) leads to 0.1% contribution for the lower range value and 7% for the upper range value.

In the reference scenario, cleaning is the third most important activity, accounting for 17% of the aggregated impact. Full substitution of aliphatic based cleaning agents with vegetable oil based ones may reduce the contribution to about 0.8% whereas full substitution of cleaning agents (except surfactants) with light aliphatic types may increase the contribution to 27%.

The 2% contribution to the aggregated impact from the repro process at the model printing company is mainly due to emission of hydroquinone (1.4%) and to lesser degree biocides (0.25%). Emissions not covered are assessed as being insignificant.

For plate making the 2.4% contribution to the aggregated impact is especially due to biocide emissions (1.7%) whereas the use of aluminium plates only contributes 0.24%. If it assumed that the model printing company uses aluminium plates based on virgin aluminium exclusively, the importance of plate making increases to 3.7% and that of aluminium to 1.5% (full allocation of the potential impact to the functional unit).

The finishing activity at the model printing company only contributes 0.43% to the aggregated impact. Processes like laminating which are included in the existing Swan ecolabelling criteria are excluded here because they normally do not take place at the printing company but at special companies (e.g. book binders). Even though inclusion of these processes might increase the importance of finishing it is assessed that the overall LCA profile for sheet fed offset printed matter will not change substantially.

As described earlier, transport has not been included as a separate activity in this generic LCA study. However based on relevant existing studies it is assessed that transport accounts for around 5% of the aggregated impact covering the whole life cycle of the generic sheet fed offset printed matter.

Especially due to lack of data, waste, i.e. nuclear waste, chemical waste, bulk waste, and slag and ashes are only treated as total amounts (kg, not differentiated by characterisation factors) in this study. However for example chemical waste from the printing company and de-inking sludge (recycling of paper) might contribute significantly to the aggregated impact of the functional unit. Furthermore, the waste treatment processes should be included in an LCA study.

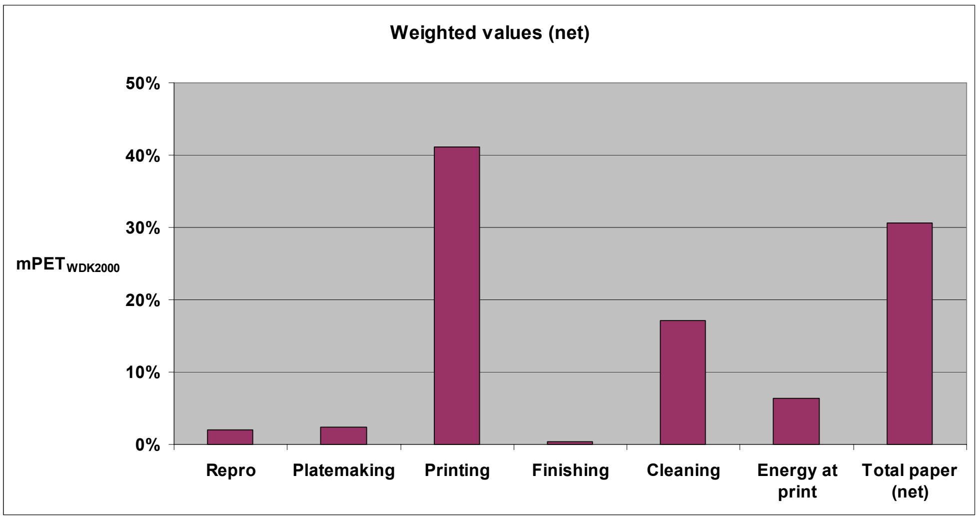
Conclusion

The goal of this study is to identify the distribution of potential environmental impacts and consumption of resources during the life cycle of generic printed matter produced on a model sheet feed offset printing company. This distribution is represented by LCA-profiles on overall results in Figures below. These results are based on average consumptions and emissions from primarily Scandinavian sheet fed offset printing companies but are assessed as being fairly representative for average modern technology in Europe. The functional unit (fu) is one ton of printed matter.

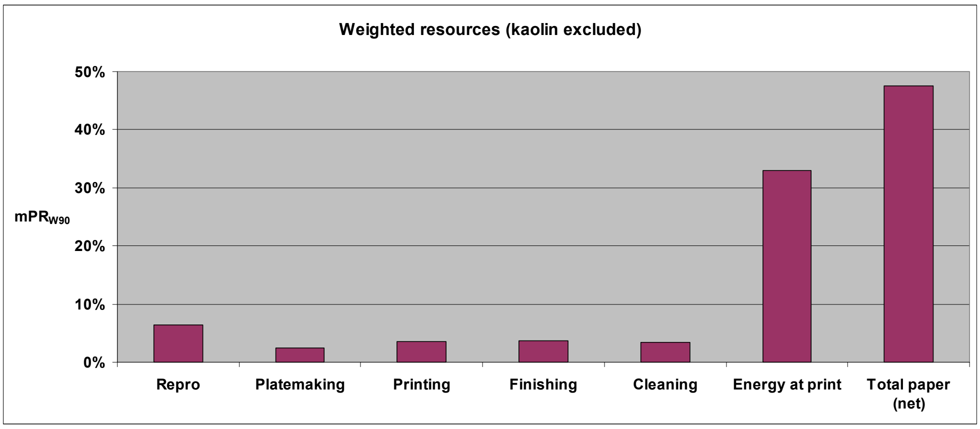
The contributions in the Figures below are divided into the activities at the model printing company. However paper is isolated because all previous studies focusing on energy related impact categories point to paper as the overall dominating factor, which is not the result of this study including the chemical related impact categories as shown in the Figures.

For the potential environmental impacts printing is dominant with a contribution of 41% (18% ink emission at the model printing company and 17% from emissions of synthesis chemicals at upstream pigment production) to the aggregated impact. Paper contributes 31% mainly due to emissions related to energy consumption.

For the aggregated weighted resource profile paper (48%) and energy consumption at the model printing company (33%) are dominant mainly due to consumption of energy carriers (natural gas and oil).



Aggregated impact profile for the reference scenario in relative figures and with total paper as net value.



Aggregated weighted resource profile for the reference scenario in relative figures and with total paper as net value and kaolin excluded.

On the basis of a sensitivity analysis including European normalisation references, weighting factors and disposal scenarios, it is concluded that the results of this LCA study are valuable for both ecolabelling of offset printed matter (especially sheet fed) on a Nordic scale (Swan labelling) and a European scale (Flower labelling).

Furthermore, on the basis of the alternative scenarios and sensitivity analysis carried out it is concluded that the strength of the LCA approach used here on ecolabelling of printed matter is not only the exact LCA profile of the reference scenario based upon average values but to a high degree the possibilities of using sensitivity analysis based upon known or theoretical ranges within values of consumption, emissions or other parameters. By conducting a sensitivity analysis we arrive at an indication of how sensitive the distribution of the potential impact within the life cycle of the printed matter is to variation in the parameter in question and thereby can find guidance in how much weight to put on the parameter in the development of ecolabelling criteria. Furthermore this LCA approach is valuable when dealing with substitution.

The main issues that it has not been possible to include fully in this study and that might change the outcome significantly include upstream emissions (e.g.

production of ink components), methane emission from land filling of paper and the fate of chemical waste (e.g. from printing company).

Research in these areas is needed if the reliability of the LCA on printed matter is to be further strengthened and thus improve the foundation for life cycle based ecolabelling criteria on printed matter.

1 Introduction

Studies dealing with product life-cycle assessments (LCA) on printed matter are relatively new. A limited number of available LCA's on offset printed matter has been produced during the last ten years, dominated by reports from framkom (former IMT) (Dalheilm & Axelsson 1995, Axelsson et al 1997, Johansson 2002) and the Danish EPA (Drivsholm et al. 1996, Drivsholm et al. 1997). There is also a study by INFRAS (1998) focusing on graphic paper which also includes print products (e.g. newspaper) as functional units.

The results from these studies all point to paper (forestry and especially pulp and paper production) as the overall dominating contributor to the potential environmental impact from the life-cycle of offset printed matter. This dominating role of paper is primarily visible in the energy-related impact categories of global warming, acidification and nutrient enrichment. All the studies focus on energy consumption including the emissions and impact categories related to energy.

Chemical related impact categories, i.e. covering ecotoxicity and human toxicity are included in the studies by Dalheilm & Axelsson (1995) and Axelsson et al. (1997) using the EPS methodology (based on the willingness to pay principle, described in Steen (1999)) as their main approach, but the degree to which emission of specific chemicals is included is not readily transparent in the documentation and the impression is that it is only done to a limited degree. The study by INFRAS (1998) also includes the chemical related impact categories by making use of the EcoIndicator-95 methodology (damage approach, based on the distance to target methodology, described in Goedkoop (1995)) and the CML method (impact or midpoint approach) based on Heijungs et al. (1992). In the INFRAS study the CML impact category on "ecotoxicity water" is included whereas the "human toxicity" and "ecotoxicity air" is excluded. Also the EcoIndicator-95 impact categories (actually effect categories) on "pesticides", "airborne heavy metals", "water borne heavy metals" and "carcinogenetic substances" are included. However for both the CML method and the Ecoindicator-95 method only emissions for which characterisation factors already existed were included (AOX an exception see Section 4.1.2.1) and therefore the study were limited in coverage. On the basis of the report INFRAS report (INFRAS 1998) it is assessed that the emissions to air included are mainly energy related ones (NOx, SO_2 etc.) and for the emissions to water mainly heavy metals and AOX (bleaching) from pulp- and paper making processes and printing. Inclusion of specific organic substances seems to be very limited. The study by Johansson (2002) does not include chemical related impact categories at all and the last study by Drivsholm et al. (1996, 1997) making use of the EDIP methodology (used in this study) only includes the emission of two substances in the impact assessment covering the chemical related impact categories.

Only in the study by Johansson (2002) is sheet fed offset included as a separate entity.

In this report we include the chemical related impact categories to a higher degree by making use of some of the latest knowledge about emissions from the production at a printing company combined with knowledge about the composition of the raw materials used during the production of offset printed matter. In some cases also upstream emissions from production of raw materials are included.

This report describes an LCA of a fictitious (or model) "typical" sheet feed printing company. The main scenario used is primarily based on the two technical background documents (Brodin and Korostenski 1995 and 1997) for the Ecolabelling of Printed Matter (Nordic Ecolabelling 2002) and the report by Larsen et al. (1995). Inventory data from six Danish sheet fed offset printing companies and published data from Danish and other European investigations are also included.

As defined in the project application and as agreed upon with the Danish EPA the LCA method used in this study is the EDIP method (Wenzel, Hauschild and Alting 1997; Hauschild and Wenzel 1998). The main reasons for choosing EDIP are that this method with its relatively simple key property based impact assessment part seems feasible for the LCA approach relevant for use in ecolabelling of products associated with many chemical emissions. Furthermore, many of the toxicity related characterisation factors for the relevant chemicals already exist in this method.

This study is done in accordance with the ISO 14040-series.

1.1 Goal and scope definition

1.1.1 Goal definition

The goal of the study is to identify the distribution of potential environmental impacts and consumption of resources during the life cycle of generic printed matter produced on a model sheet feed offset printing company in Europe. The results are to be used for developing ecolabelling criteria.

1.1.2 Scope definition

All stages of the life cycle are covered as regards the use of raw materials/energy (from material extraction to disposal when possible) but for the potential environmental impacts, the main focus is on the production stage.
The composition of composite/mixture raw material (e.g. printing ink, developers) is generic and simplified.

Average typical data have been used, i.e. not from a specific printing company with a functional unit defined in details. The data are assessed to be suitable for developing ecolabelling criteria from an LCA approach (especially if combined with sensitivity analyses).

1.1.2.1 Functional unit

Functional unit: 1 ton of sheet feed offset produced printed matter.

The printed matter is to be considered as a non-laminated average piece of printed communication covering books, pamphlets, brochures, posters, magazines and more, generically produced at a model but typical sheet fed offset printing company.

The life time of the printed matter is varying from a few weeks for advertising material to several years for books and posters. For the sake of normalisation of the LCA results, the life time is here set to one year.

1.1.2.2 Assessment criteria

The assessment criteria used here are defined as the impact categories made operational in the EDIP method (Wenzel, Hauschild and Alting 1997; Hauschild and Wenzel 1998) and include: Global warming, ozone depletion, acidification, nutrient enrichment, photochemical ozone formation, chronic human toxicity via water and soil, chronic ecotoxicity in water and soil, acute human toxicity via air, acute ecotoxicity in water, hazardous waste, nuclear waste, slag and ashes, and bulk waste. Furthermore resource consumption is included. As the life cycle of printed matter is dominated by the use of a lot of chemicals, it is important to include the chemical-related impact categories (i.e. ecotoxicity and human toxicity). Furthermore, the production of the main raw material paper is energy-demanding which makes the inclusion of the energy-related impact categories important (global warming, acidification and nutrient enrichment).

1.1.2.3 Scope definition of the product system

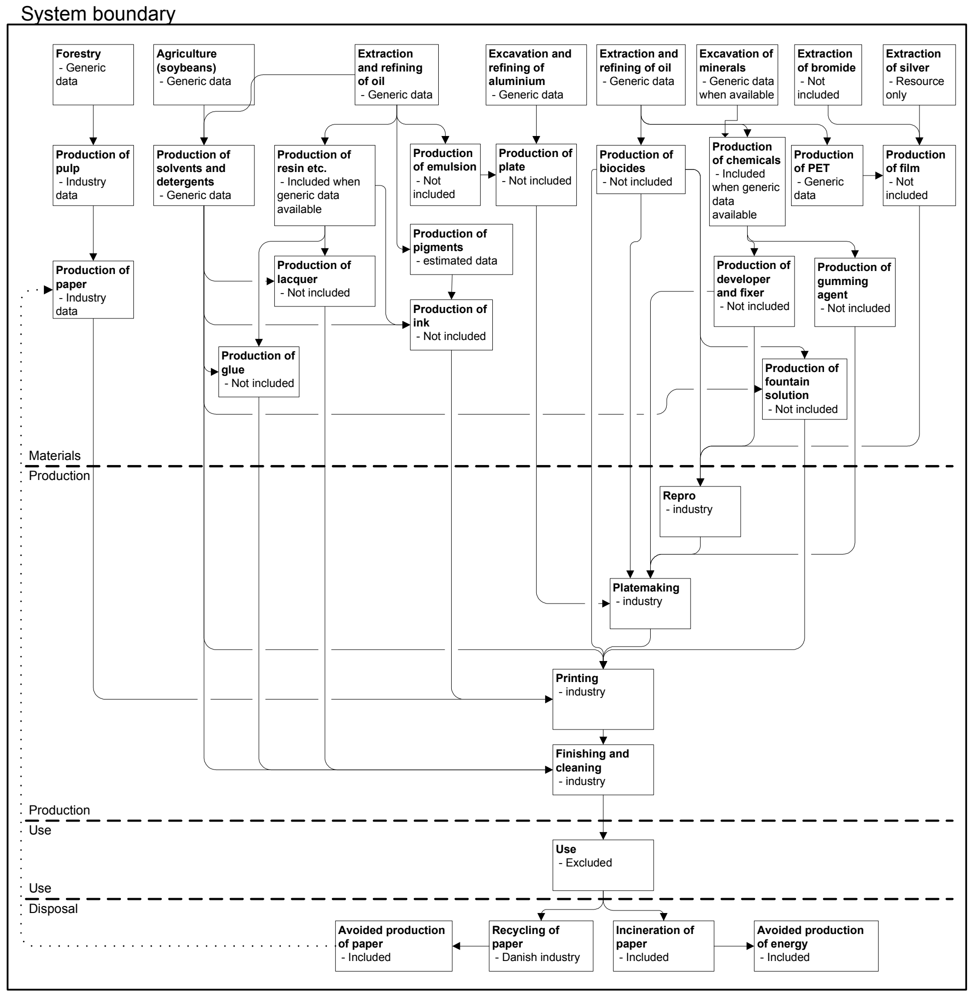


Figure 1: The product system

Due to the scope of this study, transport is only included when it is an integrated part of a unit process included (e.g. production of paper from cradle to gate). So transport of raw materials from producer to the printing company and the transport in the production, use and disposal stages are not included. However transport for recycling of paper as described in Frees et al. (2004) is included because it is an integrated part of the unit process used here. The importance of transport in the life cycle of printed matter is however assessed but mainly on the basis of existing LCA-studies, see Section 4.1.4.

For finishing, only lacquering and gluing are included. Laminating is typically not done at the sheet fed offset printing company (Brodin & Korostenski 1995) and inventory data is not readily available. Lamination is therefore excluded here. Packaging processes occurring at the printing company such as the use of wooden pallets, paper and/or "shrink plastic" are also excluded due to lack of data but they are assessed to be of very low significance as compared to the other activities.

For disposal of printed matter it is assumed that 53% of the paper consumption (including both spillage and product) is recycled and the rest, i.e. 47%, is incinerated and the heat utilised. This assumption is based on the Danish situation in 2000 (Tønning 2002). Differences in recycability of the printed matter (e.g. deinking or repulping problems due to content of hotmelt or water based inks) are not included due to lack of readily available quantitative data and the scoping of this study. A qualitative description of the issue may be found in the report "Recycling of printed products" (ECSPI 2000).

Direct and indirect overhead operations such as production of printing machines and office supplies are expected to contribute insignificantly to the overall impacts and are generally not included. However total energy consumption covering, for example, heating and lighting at the model printing company (indirect overhead operations) are included.

1.1.2.4 Time scope

The time to produce one functional unit is assumed to be a few days and the production takes place in the period 1990 – 2002. The use stage and disposal stage will for most of the printed matter take a few weeks and cover the same time period. Given that the lifetime is assumed to be one year in the functional unit, the disposal will take place in the period 1991-2003. For long-lived items like books and posters the use stage may cover several years and this would delay the disposal stage by several decades. The material stage is assumed to cover at least 1980 – 2002.

1.1.2.5 Technological scope

In general, a marginal energy approach is used in the identification of the technology applied to generate the consumed electricity, i.e. production of electricity is based on natural gas. This is because electricity consumption is increasing in Europe, and the dominant new production facilities use natural gas as an energy resource. Further arguments and description of the marginal energy approach can be found in Frees et al. (2004), and references to the exact energy unit processes used here can be found in Annex A.

The consumption of paper in Europe is increasing, which leads to a marginal approach for paper also (Frees et al. 2004), i.e. increased demand for paper will lead to paper production based on virgin fibres. So in the reference scenario the paper market is unsaturated.

The technologies used for the material stage are to some extent dependent on the unit process data that have been readily available for this study. For example for pulp and paper production, the technologies are modern and used in the Swedish pulp and paper industry in 2001 (Frees et al. 2004) for producing white paper based on ECF (Elemental Chlorine Free) sulphate pulp (virgin fibres) for use in, for example, the printing industry. References for the pulp and paper unit process and other unit processes in the material stage can be found in Annex A.

For the production stage, the technologies included in this study mainly cover the technologies used at sheet feed offset printing companies during 1990 – 2000 especially in the Nordic countries but also in Northern Europe. It is evaluated that these technologies still dominate. However, the chosen scoping excludes "new" state–of-the-art technologies. These technologies include, for example, Computer–To-Plate (CTP) and waterless offset (Silfverberg et al. 1998) which have been used to a limited degree for some years (Larsen et al. 1995) and for which the market share is still increasing (April 2004). On the other hand, technologies and techniques which are no longer used (or only used to a limited degree under controlled conditions) in Northern Europe for say 20 – 30 years are most probably still used especially in Eastern European countries. Examples of such "old" technologies and techniques could be extended use of dampening form rollers with cloth (Heber" dampening system) needing at least daily cleaning using hazardous solvent-based cleaning agents which are emitted directly to the water recipient after use (no Waste Water Treatment Plant (WWTP) or only a mechanical one). Another example could be extended use of aromatic very volatile solvents for manual cleaning of the printing machine leading to extensive exposure of workers and large air emissions. The use of cleaning agents containing more than 0.1% aromatic solvents is not considered in this study (i.e. reference scenario), and only limited use of dampening form rollers with cloth (Heber" dampening system) is included, i.e. 10-20% of the dampening systems. Emission of solvent-based cleaning agents to water is therefore very limited (0.1-1%) in the reference scenario, and only water emission of detergents used for cleaning is relatively high (50%). For description of the use of dampening form rollers with cloth see Larsen et al. (1995).

For the disposal stage the technologies used for incineration and recycling of paper are modern Northern European types.

1.1.2.6 Geographical scope

The production of printed matter is assumed to take place in Europe with a main focus on Scandinavia. As described below, wastewater treatment by wastewater treatment plants (WWTP) is not included in the reference scenario making this scenario also relevant for Southern and Eastern Europe. However, a scenario with waste water treatment (see Section 2) is also included and can be considered as relevant for Northern Europe, especially Sweden and Denmark.

For the material stage, the production of paper is assumed to take place in Sweden and the inks for printing are assumed to be produced in Europe.

Disposal and recycling are based on scenarios for Denmark. However European disposal scenarios are considered in the sensitivity analysis, see Section 4.1.2.

1.1.2.7 Allocation

For paper consumption in the reference scenario it is assumed that only paper produced from virgin fibres is used (the typical case today), and only in the scenario including a saturated paper market (see Section 2) have the energy savings from producing recycled paper instead of virgin paper been allocated to the functional unit. However, for the total paper-related potential impact (comprising forestry, pulp and paper production, and disposal of waste paper and product), the avoided potential impact from incineration of fossil fuel due to incineration of paper and the avoided potential impact from production of virgin fibres due to production based on recycles fibres are allocated to the paper and designated paper (net). The designation paper (gross) is used for the case where the avoided potential impacts are not allocated to the paper. For consumption of aluminium (offset plates) it is assumed that recycled aluminium is used and the extra energy used to produce virgin aluminium to replace the loss of 8% during the recycling process is allocated to the functional unit.

2 Inventory

The starting point for the inventory is the production stage of generic printed matter produced at a model sheet fed offset printing company. The raw materials included are described in the next section. Each raw material is divided into its components (see Section 2.1) and the resource consumption/emissions of the production of the raw material and its components (i.e. material stage) are mapped and included whenever readily available and relevant, see Figure 1. For many of the composite raw materials no data exists on production (i.e. typically a mixing process). However for their components generic data on resource consumption and emissions are available and used in many cases. In any case data on emission of specific substances at the material stage is typically not available and this kind of data is almost exclusively used in the production stage for which they have been available and focused upon in this study. Omissions that are assessed to be of possible significance are discussed later on in this report (e.g. Section 3.2. and Section 4.1.3). An overview of inventory references is given in Annex A and in Annex B data for the activities at the model printing company is shown together with data from 11 real world offset printing companies. A full aggregated inventory is shown in Annex C.

2.1 Composition of raw materials

The raw materials for the production stage included in this generic study are the dominant types typically used in ‘traditional’ sheet feed offset, i.e. film, film developer, fixer, biocides, plates, plate developer, gumming solution, paper, alcohol (isopropyl alcohol, IPA), printing ink, fountain solution, lacquer (varnishes), glue and cleaning agents. The composition of these raw materials is as far as possible based on known typically recipes as described in Larsen et al. (1995) in Danish and published in a short English version (Larsen et al. 1996). Other reports, articles and updated MSDS’s from suppliers/producers on relevant raw materials have also been consulted. However, due to lack of data (e.g. toxicity data) assumptions about the components have had to be made as shown below.

2.1.1 Film

The thickness of the film is assumed to be 0.1 mm (KODAK 2001a), the silver content 10 g/m^2 and the content of halides (assumed to be bromide) 7 g/m^2 (Baumann & Gräfen 1999a). The 0.1 mm thick base layer consists of polyethylene, PET (i.e. poly(ethylene terephthalate) (KODAK 2001a, Lapp et al. 2000). Other components such as gelatine and components with minor occurrence (i.e. well below 1% w/w) like filter dyes, fungicides and wetting agents, are excluded. As the density of PET is 1370 kg/m^3 (APR, 2003) the generic film is assumed to consist of 89% w/w polyethylene, 6% w/w silver and 5% w/w bromine.

2.1.2 Film developer

The composition of the film developer is based on KODAK RA 2000 Developer (KODAK 2001b, 2003) and shown in Table 1. This developer is known to be used within the repro process at Danish sheet feed offset printing companies and its composition is in accordance with the general description of developers in Seedorff (1993).

Table 1. Composition of generic film developer. Working solution.

Component	% w/w
Water	91
Potassium sulphite	3.5
Diethylene glycol*	2.0
Hydroquinone	1.8
Sodium sulphite	0.76
Sodium carbonate	0.76
4-hydroxymethyl-4-methyl-1-phenyl-3-pyrazolidinone	0.25

* For upstream production data substituted by ethylene glycol

2.1.3 Fixer

The composition of the fixer is based on KODAK 3000 Automix Fixer (KODAK, 2000, 2003) and shown in Table 2. This fixer is known to be used within the repro process at Danish sheet feed offset printing companies and its composition is in accordance with the general description of fixers in Seedorff (1993).

Table 2. Composition of generic fixer. Working solution.

Component	% w/w
Water	81
Ammonium thiosulphate	14
Sodium acetate	2.6
Boric acid	0.66
Ammonium sulphite	0.66
Acetic acid	0.66
Sodium bisulphite	0.33

2.1.4 Biocides

When rinsing water for film developing and plate making are recycled, biocides (algicides, fungicides, bactericides) are typically used (Kjærgaard 1997). One of the dominant types of biocides used within the printing industry is the group of isothiazolines, which in many cases is represented by Kathon® consisting of three parts 5-chloro-2-methyl-isothiazolin-3-one (CMI) and one part 2-methyl-2-isothiazolin-3-one (MI) (Larsen et al. 1995, 2002, Andersen et al. 1999, Gruvmark 2004). The product Nautalgin C1 (Deltagraph 1997) which is used as a biocide agent when recycling rinsing water contains about 1-2% CMI, 0.1-1% MI and water. The generic biocide agent used here for conservation of recycled rinsing water in film developing and plate making is therefore assumed to be water-based and containing 2% w/w CMI and 0.67% w/w MI. In Section 2.4.6 biocide agents used in the printing industry are further described.

Biocides occurring as part of raw materials (e.g. fountain solutions) are dealt with below.

2.1.5 Plates

The generic plate considered in this study is a mono-metal-positive-plate (aluminium), which is known to be used within sheet, fed offset plate making (Larsen et al. 1995). According to information from Hoechst (1994) on Ozasol® plates, the thickness of offset plates is in the range of 0.12 - 0.5 mm. Here we use the average 0.3 mm. As the density of aluminium is 2700 kg/m^3 (IAI 2003) the mass of aluminium per square meter plate is 0.81 kg.

The emulsion layer on top of the plate has a thickness of 3 µm according to Baumann and Gräfen (1999b). The density of the emulsion is estimated to be 1230 kg/m^3 on the basis of a weighted average (2:1) of the density (1200 kg/m^3) of low molecular phenol formaldehyde resin (Muskopf 2000) and the density (1300 kg/m^3) of polyvinyl alcohol (Baumann & Rothardt 1999). The mass of the emulsion per square meter therefore lies close to 4 g/m^2 (3.7 g/m^2). According to Ludwiszewska (1992) the range is 1.5 g/m^2 - 4 g/m^2 plate, but for positive plates in most cases near the highest value.

So based on the figures estimated above, the generic offset plate is assumed to be composed of 99.5 % aluminium and 0.5% emulsion. The generic emulsion is assumed to have the composition shown in Table 3 (Larsen et al. 1995, KODAK 2002a).

Table 3. Composition of generic offset plate emulsion.

Component	% w/w
Phenol formaldehyde resin*	64
Polyvinyl alcohol	34
2-diazo-1(2H)-naphthalinone derivate	1
Other additives**	1

* For upstream production, data substituted by alkyd resin
** For example pigments

2.1.6 Plate developer

The composition of the generic developer is shown in Table 4 and based on Larsen et al. (1995).

Table 4. Composition of generic positive offset plate developer

Component	% w/w
Water	90
Disodium metasilicate	8
Sodium hydroxide	2

2.1.7 Gumming agent

The composition of the generic gumming agent used in this study (see Table 5) is based on UNIFIN (Agfa 2002) which is known to be used within sheet fed offset and Larsen et al. (1995).

Table 5. Composition of generic gumming agent.

Component	% w/w
Water	85
Carboxy methyl cellulose (CMC)	5
Sodium-dodecyl-diphenyloxide-disulphonate	5
Citric acid	5
5-chloro-2-methyl-isothiazolin-3-one	0.1
2-methyl-2-isothiazolin-3-one	0.033

2.1.8 Paper

The generic paper used in the reference scenario in this study is a white uncoated fine type paper produced from sulphate pulp based on virgin fibres as defined in the Danish draft report on recycling of paper and card board (Frees et al. 2004).

Another scenario considers the use of recycled paper at the model printing company Cycluspaper produced at the Danish paper mill Dalum Papir A/S and based on 100% recycled fibres (Frees et al. 2004). Even though coated paper like MultiArt Silk and Multiart Gloss from PAPYRYS has a widespread use within sheet fed offset printing, the coating process is excluded here. This is due to lack of readily available data, and the assessment that the coating process most probably is insignificant for the environmental impact as compared to the other processes included in the production of paper.

2.1.9 Alcohol (IPA)

The alcohol added to the fountain solution is typically 2-propanol (isopropyl alcohol, IPA) or a mixture of IPA (10%) and ethanol (90%) called IPA-spirit (Miljønet 2004). In this generic LCA, pure IPA is chosen.

2.1.10 Printing ink

Several different pigments, some different binders and solvents, and several types of additives are used in sheet feed offset printing ink. The generic composition shown in Table 6 has been chosen, mainly based on Larsen et al. (1995).

Table 6 Composition of generic sheet fed offset printing ink

'Typical' composition		Upstream inventory substitute		Downstream inventory substitute	
Component	% (w/w)	Component	% (w/w)	Component	% (w/w)
Pigment Yellow 12 and 13 (P.Y. 12 and 13)	6	P.Y. 14	6	P.Y. 12	6
Pigment Blue 15:3 (P.B. 15:3)	5	P.B. 15	5	P.B. 15	5
Pigment Red 57:1 (P.R. 57:1)	5	P.Y 14 and P.B. 15	5	P.R. 57:1	5
Pigment Black 7 (P.B 7, Carbon Black)	3	P.B. 7	3	P.B. 7	3
Modif. phenol resin	20	Alkyd resin	20	Alkyd resin	20
Soya oil alkyd	12	Alkyd resin	12	Alkyd resin	12
Soya oil	12	Soya oil	12	Soya oil	12
n-paraffin (heavy)	29	n-paraffin (heavy)	29	Tetradecane	29
Poly ethylene wax	3	Poly ethylene wax	3	Poly ethylene wax	3
Additives (incl. siccatives)	5	excluded	excluded	excluded	excluded

Besides the composition of the ink, the upstream and down stream inventory substitutes are also shown in Table 6. "Upstream inventory substitute" means the chemical on which the inventory upstream from the production stage (not including the production stage) is based. "Downstream inventory substitute" similarly means the chemical on which the inventory from production stage (included) and downstream is based. The reason for this division is that in many cases, upstream data are only available for certain substances or mixtures (e.g. modified phenol resin) within a functional group (e.g. binders) and furthermore, these data typically only include resource and energy consumption, and emissions given as "sum parameters" (e.g. COD, BOD) and not emissions of single substances. However, for the production stage we typically have a better knowledge of the composition of the raw materials, and individual substances can therefore be used when assessing emission from this stage and downstream if data on potential impact is available for these substances.

The pigments included in Table 6 ("typical" composition) are the most frequently used according to Larsen et al. (1995). The relative distribution within the group of pigments is based on an example from Baumann & Rothardt (1999) concerning a leaflet with 50 % area printed in four colour (half-tone; 20% black, 70% yellow, 50% blue, 50% red) and 20% area of text (15% black). The relative distribution of each pigment type is corrected for the different content of pigments in the different coloured printing inks according to Larsen et al. (1995).

The mix of pigments shown in Table 6 does not exist in any printing ink but should be seen as an attempt to reflect an approximation of the average relative consumption of pigments for producing generic printed matter by sheet fed offset. It may be relevant to look at a significantly higher relative consumption of carbon black (dominating in production of books) but this is not included in this study.

Pigment Yellow 12 (P.Y. 12), P.Y. 13 and P.Y 14 are all diaryl (diazo) pigments based on dichloro benzidine. The only difference in structure is the number of methyl groups, i.e. P.Y. 12 (no group), P.Y. 13 (four groups) and P.Y 14 (two groups) (Baumann & Rothardt, 1999). It seems unlikely that these differences would give rise to major significant differences in inventory data and environmental properties. Furthermore, P.Y. 14 (for which inventory data is available) is actually used in offset printing inks but to a much lesser extent than P.Y. 12 and P.Y 13 (Baumann & Rothardt, 1999).

Pigment Blue 15:3 (P.B. 15:3) is substituted by P.B. 15. Both of them are copper phthalocyanine pigments with only minor differences in structure, e.g. different crystal modification (Herbst & Hunger, 1993) and they share the same CAS number.

Pigment Red 57:1 (P.R. 57:1) belongs to the group of BONA (beta-oxynaphtoic acid) pigment lakes, which are monoazo pigments (Herbst & Hunger, 1993). This structure is quite different from the structure of the two substitutes (i.e. P.Y. 14 and P.B. 15) so this substitution is only justified by lack of data.

Carbon Black is not substituted.

Binders included comprise the dominant hard resin: Modified phenol resin, the alkyd resin: Soya oil alkyd, and the drying oil: Soya oil (actually semi-drying). No data is available on the modified phenol resin or the soya oil alkyd, and both of them are substituted by general alkyd resin.

The solvent n-paraffin (heavy) is substituted by one of its components tetradecane (Hansen & Gregersen 1986) for the inventory/impact assessment downstream.

Additives, e.g. siccatives and antioxidants, are excluded due to data lack and further commented in Section 3.2.

2.1.11 Fountain solution

The composition of the generic fountain solution concentrate is shown in Table 7. This composition is based on MSDS of two products from Akzo Nobel (2003a), Akzo Nobel (2004) and Larsen et al. (1995). The full recipe for a fountain solution is very complex (Larsen et al. 1995), and only the known main components and very toxic components are included in Table 7. Other constituents like acids, surface active substances, corrosion inhibitors and more are excluded due to lack of data and these substances probably do not contribute significantly because they occur in very low quantities and/or are not very toxic, see Section 3.2 for further comments.

Table 7. Composition of generic fountain solution concentrate.

Component	% w/w
Water	94
IPA	3
Diethylene glycol*	3
2-brom-2-nitropropan-1,3-diol (Bronopol)	0.25
5-chloro-2-methyl-isothiazolin-3-one **	0.045
2-methyl-2-isothiazolin-3-one **	0.015

* For upstream production data substituted by ethylene glycol
** Part of Kathon

Fountain solution concentrates registered at the Danish Ecolabelling Agency all contain Kathon at the same concentration level, i.e. 0.0475%, 0.055% and 0.06%, and one type also contains 0.1% Bronopol (Gruvmark 2004).

2.1.12 Lacquer

Three main types of lacquer are used within finishing of sheet fed offset printed matter, i.e. water based lacquer, “offset lacquer” and UV lacquer. Consumption of water based lacquer (dispersion lacquer) is dominant, accounting for at least 80% (Brodin & Korostenski 1995, 1997) and water based lacquer is also used to a high degree as “anti-set-off-agent” in the printing process (Larsen et al. 1995). UV lacquer is excluded here due to lack of readily available data.

The composition of the generic water based lacquer is shown in Table 8 and based on Larsen et al. (1995, 2002), Andersen et al. (1999) Akzo Nobel (2003b) and Akzo Nobel (2004). Known potential components like anti foaming agents and softeners are excluded due to lack of data and further commented on in Section 3.2.

Table 8. Composition of generic water based lacquer.

Component	% w/w
Water	66
Acrylates (poly-, mono-, esters)	25
Glycerol	3
Ethanol	2
Ammonia	1
Polyethylene wax	1
2-amino-ethanol	1
Alcoholethoxylate*	1
Chloracetamide	0.04

* Here represented by undecyletherpolyoxy-ethylene (5)

According to Gruvmark (2004), water-based lacquers registered at the Danish Ecolabelling Agency either do not contain biocides or 0.016% – 0.025% chloracetamid or 0.005% – 0.007% bronopol.

The composition of the generic “offset lacquer” is shown in Table 9 and resembles a sheet fed offset printing ink without pigments.

Table 9. Composition of generic "offset lacquer".

Component	% w/w
Modified phenol resin*	24
Soya oil alkyd *	14
Soya oil	14
n-paraffin (heavy)**	40
Poly ethylene wax	3
Additives (incl. siccatives)***	5

* Substituted by general alkyd resin for upstream production
** Substituted by tetradecane for downstream inventory
***Excluded due to lack of data.

2.1.13 Glue

The only glue included here is Hot melt. It is very frequently used within the printing industry (Miljønet 2004) for finishing of catalogues, magazines and paperbacks (Brodin & Korostenski 1995, 1997; (Miljønet 2004) and in combination with dispersion glue for finishing of books. The generic composition of Hot melt is shown in Table 10 and based on the Hot melt product Superflex 225 (After Print 1983), Brodin & Korostenski (1995, 1997) and (Miljønet 2004). Antioxidants are excluded due to lack of data.

Table 10. Composition of generic Hot melt.

Component	Substitute	% w/w
EVA (Ethylene-vinyl-acetate)	LDPE (Light Density Polyethylene)*	38
Modified resin or rosin	Alkyd resin**	48
Wax	Polyethylene wax***	14
Antioxidants	Excluded	0.15

* Assumed to be the main component in EVA (Schmidt et al. 1993)
** A modified resin like phenol formaldehyde resin is, as in the case of the generic printing ink, substituted by alkyd resin here.
*** It is assumed here that wax can be represented by polyethylene wax which is often used in wax containing raw materials for the printing industry (Larsen et al. 1995).

2.1.14 Cleaning agents

Different types of cleaning agents are used in a sheet fed offset printing company. The main types include heavy aliphatic (paraffin based, low volatilization), light aliphatic ("ekstraktions benzin", highly volatile), vegetable oil based, alcohol based, types based on surfactants, and different mixtures of these (Larsen et al. 1995, Akzo Nobel 2003c, Akzo Nobel 1998). Surfactants are both included in detergent-based types like shampoos and in pasta for cleaning rollers and as emulsifiers in some solvent-based types (Ludwiszewska 1992; Larsen et al. 1995). Destructors (ink removers) which are only used to a very limited degree (Larsen et al. 1995) are excluded here.

Table 11. Types of cleaning agents included in the study.

Type	% of total use*	Upstream inventory component	Downstream inventory substitute
Heavy aliphatic	24.5	n-paraffin's (heavy)	Tetradecane**
Light aliphatic	24.5	n-paraffin's (light)	Hexane (0.1% benzene)***
Vegetable oil based	24.5	Soya oil	Soya oil
Alcohol based	24.5	Ethanol	Ethanol
Surfactants	2	Alcohol ethoxylates	Undecyletherpolyoxy-ethylene (5)

* It is assumed here that the surfactants only account for around 2% (Larsen et al. 1995) and that the rest is shared equally between the other types.

** Tetradecane is a component of aliphatic mixtures (C10 – C14) with distillation interval: 180 – 300°C (Danish: Petroleum).
***Hexane is a component in aliphatic mixtures (C5 – C9) with a distillation interval of 60 – 140°C, i.e. “ekstraktions benzin” (Hansen & Gregersen 1986; Larsen et al. 1995) known to contain limited amounts (ca. 0.1%) of aromatics (Hansen & Gregersen 1986) here assumed to be benzene at its threshold value (0.1%) for classification when occurring in mixtures (ECC 1967 and its amendments, e.g. EC 2001).

The relative share of each of the cleaning agent types in Table 11 is assumed but supported by Larsen et al. (1995), Anonymous 1 (2000) and Anonymous 6 (2002). At one sheet fed printing company (Anonymous 1 2000) using widely used products, i.e. Synvex, Vegeol, Solvask and “ekstractions benzin” the exact distribution (%w/w) excluding surfactants is known, i.e. heavy aliphatic (21%), light aliphatic (23%), alcohol (29%) and vegetable oil based (27%). Based on these arguments the distribution in Table 11 is assessed to represent the average situation for sheet fed printing companies fairly well, at least in the Nordic countries.

2.2 Consumption of raw materials

The consumption of raw materials in the material stage and the disposal stage are taken into account to a degree defined by the unit processes included and generally not as detailed as the consumption at the production stage. For example, if we look at the paper production, raw materials included are mainly kaolin and wood but not, for example, adhesives and auxiliary materials (e.g. biocides), which are commented upon in Section 4.1.3.1.

The consumption of the raw materials and energy at the production stage is shown in Table 12.

Table 12. Consumption at the model sheet fed offset printing company; kg or m^2 per functional unit (fu). Values used in reference scenario in bold

Material/chemical	Phase	Amount per fu (range in brackets) (Brodin and Korostenski 1995)	Amount per fu (range in brackets) *
Film (m^2/fu)	Repro	-	**5.63** (1.9 – 9.76)
Film developer (kg/fu)	Repro	**2.85** (1.19 – 6.00)	1.77 (0.1 – 3.63)
Fixer (kg/fu)	Repro	**3.17** (1.25 – 9.66)	3.58 (0.66 – 9.4)
Biocide agent (kg/fu)	Repro	-	**0.00019** (0.000008 – 0.00039) #*
Water for rinsing (kg/fu)	Repro	-	**5.77** (0.24 – 11.6)
Plate (Al) (m^2/fu)	Plate making	-	**4.16** (1.0 – 8.45)
Plate emulsion (kg/fu)	Plate making	-	**0.015** (0.0037 – 0.031)**
Plate developer (kg/fu) ##	Plate making	**0.90** (0.50 – 1.4)	1.22 (0.094 – 3.5)
Gumming agent (kg/fu)	Plate making	-	**0.030** (0.0052 – 0.055)
Biocide agent (kg/fu)	Plate making	-	**0.0012** (0.00056 – 0.0018) #*
Water for rinsing (kg/fu)	Plate making	-	**37.4** (16.7 – 54.0)
Paper (kg/fu)	Printing	1100 §§§ (1030 – 1190)	**1200**§ (1030 – 1470)
Printing ink (kg/fu)	Printing	**5.8** (1.8 – 14)	12.1 (4.5 – 26.5)
IPA (kg/fu)	Printing	**3.93** (0.0785 – 5.18)	4.85 (2.84 – 10.4)
Fountain solution (kg/fu)	Printing	-	**1.00** (0.474 – 1.90)
Water for dilution (kg/fu)	Printing	-	**29** (11 – 46)
Cleaning agents total (kg/fu)	Cleaning	-	**2.50** (0.30 – 10.6)
- veg. oil based (kg/fu)	Cleaning	-	**0.61** (0.05 – 2.56) ###
- organic solv. based (kg/fu)	Cleaning	-	1.10 (0.56 – 2.33)
- aliphatic based (kg/fu)	Cleaning	-	**0.61**
- "ekstraktionsbenzin" (kg/fu)	Cleaning	-	**0.61**
- alcohol based (kg/fu)	Cleaning	-	**0.61**
- detergent based (kg/fu)	Cleaning	-	**0.05** ***
Water for rinsing (kg/fu)	Cleaning	-	**22** (0.26 – 65)
Water based lacquer (kg/fu)	Finishing	§§	**4.98** (0.51 – 6.97)
Offset lacquer (oil based) (kg/fu)	Finishing	§§	**0.22** (0.006 – 0.38)
Hotmelt glue (kg/fu)	Finishing	-	**0.75** (0.067 – 1.44)
Energy consumption (kWh/fu)	Total general	-	1210 (768 – 1620)
- electricity (kWh/fu)	General	-	**705** (629 – 858)
- district heating (kWh/fu)	General	-	**176** (0 – 765)
- fuel oil (kWh/fu)	General	-	**243** (0 – 486)
- natural gas (kWh/fu)	General	-	**83.9** (0 – 304)
Water (kg/fu)	Total general	-	**1160** (385 – 2690)

* Based on inventory data from eleven offset printing industries: One sheet fed, one heatset and one cold-set-newspaper (Larsen et al. 1995), six sheets fed (Anonymous 1-6: Danish printing companies data from 1999, 2000 and 2002) and two cold-set-newspaper (Axelsson et al. 1997), see Annex B

** Estimated on basis of consumption of plate area and amount of emulsion per square meter (3.7g/m^2) (Baumann & Gräfen 1999b)

*** Larsen et al. 1995

Kathon a.i.. Estimated on basis of content in rinsing water and rinsing water consumption.

Density of Goldstar Developer (Kodak 2002b) used.

Actual average of range is 0.87 but only 24.5% of total (0.245*2.5=0.61kg/fu) is allocated, see Table 11

§ Spillage of paper for recycling 16% (4.5% - 32%)

§§ Total lacquer consumption 5.6 (3.2 – 8)

§§§ Spillage of paper for recycling 9.6% (3.3% - 19%)

The consumption figures used in the generic LCA are as far as possible based on data from the technical background document for the Swan criteria (Brodin and Korostenski 1995). However, in most cases data are missing and the investigation conducted in this project is used, see Table 12. For paper consumption, the average value calculated in this study is used instead of the average value in Brodin & Korostenski (1995) because the value from the technical background document seems far too low, at least in the Danish printing industry according to three anonymous Danish sheet fed offset printing companies (Anonymous 4-6 2003) and the Graphic Association Denmark (Bøg

2003). Large difference (a factor of 15) is also seen for ink consumption, which is dealt with in a sensitivity scenario.

The consumption of biocides for film developing and plate making is estimated on the basis of the average rinsing water consumption (se Table 12), and information on a typical dose of around 50 ml per 40 l rinsing water (Cederquist 2004) of a biocide agent i.e. Nautalgin C1 (Deltagraph, 1997) with a known biocide content (around 2.7% Kathon®). On this basis, the biocide active ingredient (a.i.) in the rinsing water can be estimated to 33 ppm.

2.3 Emissions

Emissions to air, water (and soil) from the material stage and the disposal stage are taken into account to a degree defined by the unit processes included and generally far from as detailed as the emissions at the production stage.

The emissions from the production stage included in this study are shown in Table 13.

Table 13. Emitted fractions of different materials and substances for the model sheet fed offset printing company (percentage of consumption). Figures used in bold.

Material/chemical	% to air	% to waste water	% to chemical waste	% waste for incineration	% to recycling	% with product
Film						
PET (89% w/w)	0	0	0	100	0	0
Ag (6% w/w)	0	0.43 (0.020 -0.72)	0	0	99.6	0
Br (5% w/w) *	-	-	-	-	-	-
Film developer	0	4.2	0	0	95.8	0
Fixer	0	19	0	0	81	0
Biocide agent (repro)	0	100	0	0	0	0
Plate (Al)	0	0	0	0	100	0
Plate emulsion	0	24	36		(40)**	0
Plate developer	0	40	60	0	0	0
Gumming agent	0	100	0	0	0	0
Biocide agent (plate making)	0	100	0	0	0	0
Paper	0	0	0	0	16 ***	84
Printing ink	0	1	20	0	0	80
IPA	86	14	0	0	0	0
Fountain solution agent						
IPA	86	14	0	0	0	0
Glycol + biocides	0	100	0	0	0	0
Cleaning agents						
- veg. oil based	0	1	99	0	0	0
- organic solv. based						
- aliphatic based	70	1	29	0	0	0
- extractionsbenzine	95	0.1	4.9	0	0	0
- alcohol based	95	1	4	0	0	0
- detergent based	0	50	50	0	0	0
Water based lacquer	0	5	0	0	0	95
Offset lacquer (oil based)	0	0.1	20	0	0	79.9
Hotmelt glue#	-	-	-	-	-	-

* Excluded due to lack of data
** Assumed to be incinerated during recycling process of aluminium
*** Actually this is the paper spillage/waste at the printing company gathered with the purpose of recycling. However as for the paper that is part of the product it is assumed that 53% is recycled and 47% is incinerated according to the Danish situation in 2000 on general recycling of paper (Tønning 2002).
#Quantitative useful data on emission of Hot melt during use is not readily available. But based on the qualitative description in MiljøNet (2004) it probably primarily contributes to potential occupational health and safety problems in the workers' environment which is not included in this LCA. However air emission of organic solvent components and other organic substances created during the heating process may contribute to LCA impact categories like photochemical ozone formation and human toxicity via air.

Emission of silver to water is estimated on basis of data from the technical background document (Brodin & Korostenski 1995) i.e. a relative coverage of ion exchange equipment of 22% leading to an average emission of 42 mg Ag/m^2 film.

Water emission of film developer is also estimated on basis of Brodin & Korostenski (1995), i.e. the typical value 0.02 l film developer/m^2 film. Density of developer is assumed to be 1.055 kg/m^3 (KODAK 2001b).

Also for fixer, the water emission is calculated on basis of Brodin & Korostenski (1995) with a typical value of 0.08 l/m^2 and an assumed density of 1.31 kg/m^3 (KODAK 2000).

As it is assumed that the rinsing water for film developing and plate making is preserved with biocide agent and after recycling is emitted as wastewater to the sewage system, the biocide agent emission to water becomes 100%.

For the offset plate, it is assumed that 100% of the aluminium is recycled, and for the plate emulsion 60% ends up in the developer of which 40% ends up in the rinsing water (Larsen et al. 1995). As it is assumed that the rinsing water after recycling is emitted to the sewage system, 24% of the emulsion is emitted to water. The remaining 36% is disposed of as chemical waste together with the used developer.

Gumming solution typically ends up in either rinsing water during the plate making process (Anonymous 5 2003) or in the fountain solution during printing (Larsen et al. 1995). As both rinsing water and fountain solution are assumed to be emitted to the sewage system 100% of the gumming solution is emitted to water.

For paper, the spillage/waste amount for recycling is set to 16%. The rest follows the product (see Table 12 and Table 13). It is assumed that 53% of the paper consumption (including both spillage and product) is recycled and the rest i.e. 47% is incinerated and the heat utilised. This assumption is based on the Danish situation in 2000 (Tønning 2002).

Printing ink emitted to water (e.g. via fountain solution) is assumed to be 1% of ink consumption (Larsen et al. 1995). The percentage ink disposed as chemical waste is estimated to 20% (range: 2.4% – 45.9%) on the basis of data from Larsen et al. (1995), Anonymous 1- 2 (2000), Anonymous 3 (2002) and Anonymous 5 (2003).

86% of the IPA consumption is assumed to be emitted to air, either as a separate chemical or as part of the fountain solution agent (Larsen et al. 1995). The rest (14%) is assumed to be emitted to the sewage system as part of the used fountain solution. All other components of the fountain solution (biocides and diethylene glycol) are assumed to be fully (100%) emitted to water.

For cleaning agents (see Table 13), the emissions to air and water are mainly based on Larsen et al. (1995), and the rest is assumed to be disposed of as chemical waste. As a minor part of the cleaning is done on dampening form rollers with cloth, 50% of the surfactants are assumed to be emitted to water. The rest is assumed to be part of cleaning agents (e.g. as emulsifiers in solvent based types) for which emission to water is very limited (0.1 – 1%) (Larsen et al. 1995). However, as low/none volatile solvents may be part of detergent based types for cleaning dampening form rollers with cloth, emission to water of vegetable oil and low volatile aliphatics is set to 1% whereas emission to water of the highly volatile “ekstraktions benzin” is set to 0.1%. Emission of alcohol to water is set to 1% because of high water solubility. The part of the cleaning agent not emitted to air or water is assumed to be disposed of as chemical waste.

On the basis of data from Anonymous 4 (2003), the part of water-based lacquer emitted to water is set to 5% of consumption (due to both cleaning and disposal of lacquer waste). The rest is assumed to be part of the product. For the offset lacquer (oil based) the emission to water is assumed to be only 0.1% of consumption due to a lower number of cleaning cycles (no colour change) and handling of waste as chemical waste (Larsen et al 1995).

2.4 Scenarios

The inventory data described above are used in the reference scenario. A number of alternative scenarios based on the reference scenario but with changes in some of the parameters, are described below.

2.4.1 Scenario 1: Average energy

As described earlier, the reference scenario is based on a marginal electricity approach where electricity production is based 100% on natural gas. However, in a previous LCA study also on offset printed matter (Drivsholm et al. 1996, Drivsholm et al. 1997) an average electricity approach is used, e.g. average Swedish electricity production in 1990 is used for electricity consumption related to the paper production. In the Swedish electricity scenario, nuclear energy production is dominant (67.8%) together with water power (26.5%). In order to be able to compare the LCA profile from this study with the profile from the former study, a Swedish energy scenario is also used in scenario 1 in this study. In addition, a Danish average electricity scenario based on data from 1997 is used in scenario 1 for the electricity consumption at the model printing company. References for the different energy approaches are compiled in Annex A.

2.4.2 Scenario 2: Saturated paper market

The reference scenario is, as described earlier, based on an unsaturated market for recycled paper. However, a comparison between generic offset printed matter based on recycled paper and a virgin paper based type will give no difference if the “unsaturated paper market” approach is used. In scenario 2 the market for recycled paper is assumed to be saturated, leading to a situation where additional use of paper leads to use of more recycled paper rather than production of virgin paper. In this scenario, the printed matter production based on recycled paper will draw the in and output for recycled paper production and thus, for example, benefit from the lower energy consumption for producing the recycled paper (as compared to virgin paper). The references for the paper recycling unit process are shown in Annex A.

2.4.3 Scenario 3: Variation in paper spillage

In order to investigate the effect of differences in paper consumption (e.g. due to variation in percent spillage/waste) on the LCA profile, scenarios with 3.3% paper waste and 32% paper waste respectively are carried out and compared. All other parameters are the same as for the reference scenario and the two tested paper consumptions are taken from the observed extremes, see Table 12. Even though a higher spillage of paper may lead to a higher consumption of ink this is not included here because we want to look at the paper separately and we do not know the size of the extra ink consumption. Variation in ink consumption is dealt with below.

2.4.4 Scenario 4: Variation in printing ink consumption

To investigate how much changes in consumption of ink (e.g. due to reduction in printing ink spillage/ink waste) alter the LCA profile, a scenario with 1.8 kg ink/fu is compared with a scenario with 26.5 kg ink/fu. All other parameters are the same as for the reference scenario and the two tested ink consumptions are taken from the observed extremes, see Table 12.

2.4.5 Scenario 5: Waste water treatment included

The reference scenario does not take treatment of the wastewater in wastewater treatment plants (WWTP) into account. Especially in Denmark and Sweden, but also to a high degree in northern Europe, wastewater is treated in WWTP (including a biological step, i.e. biodegradation) before emission to the water recipient. But in southern Europe, and especially in Eastern Europe, treatment in WWTP is not that widespread. An indication of the differences can be found in the TGD (EC 2002) showing that the proportion of the population served by WWTP in Denmark and Sweden in 1995 was 99% and 95% respectively whereas the figures for Greece and Portugal show 34% and 21% respectively.

The substances emitted to waste water during the production stage, which may contribute significantly to the impact categories including ecotoxicity are the biocides (benzalkonium chloride, Kathon and Bronopol), tetradecane, pigments (P.Y. 12, P.R. 57:1 and P.B. 15) and surfactants (sodium-dodecyl-diphenyloxide-disulphonate, undecyletherpolyoxyethylene (5)). Benzalkonium chloride is only used in scenario 6 (see section 2.4.6). The fate of these substances in a WWTP with a biological step (for biodegradation) is shown in Table 14

Table 14. Fate in a WWTP of different substances used in the printing production process

Substance	% mineralized (biodegraded)	% ending up in sludge	% to air	% to water recipient	Based on
Benzalkoniun chloride	0	90	0	10	Boethling 1984 *
CMI (part of Kathon)	41	0	0	59	Estimated **
MI (part of Kathon)	41	0	0	59	Estimated **
Bronopol	41	0	0	59	Estimated **
Tetradecane	3	85	6	6	Estimated **
Hexane	29	15	44	12	Estimated **
Hydroquinone	67	0	0	33	Estimated **
Pigment Yellow 12	0	95	0	5	Estimated **
Pigment Red 57:1	0	4	0	96	Estimated **
Pigment Blue	0	95	0	5	Estimated **
Sodium-dodecyl-diphenyloxide-disulphonate	65	33	0	2	Feijtel et al. 1995 ***
Undecyletherpolyoxyethylene (5)	69	29	0	2	Feijtel et al. 1995 ****

* Based on general data for quaternary ammonium compounds

** Estimated on basis of Appendix II in the TGD Part II (SimpleTreat 3.0) (EC 2002)

*** Based on general data for linear alkyl benzene sulphonates (LAS)

**** Based on general data for alcohol ethoxylates (AEO)

2.4.6 Scenario 6: Alternative biocide agent for rinsing water

As shown in Table 15, different biocides at different concentrations are used for preserving rinsing water. The highest recommended dose is for one of the benzalkonium chloride containing agents. Benzalkoniun chloride is at the same level of toxicity to aquatic living organisms as the components of Kathon and furthermore considered as non-inherently biodegradable.

Table 15. Biocide agents used for preservation of rinsing water in the printing industry in Scandinavia. Based on Gruvmark (2004) if not otherwise stated.

Product	Biocide type	Biocide conc. % w/w	Dosing	Resulting (max.) conc. in rinsing water (ppm)
Nautalgin*	Kathon	2.67	50 ml in 40 l water	33
Anonymous A	Kathon	?	?	?
Anonymous B	Kathon	0.5 - 5	?	?
Anonymous C	Kathon	1	15-20 ml in 25 l water	8
Anonymous D	Benzalkonium chloride	5	1-2 dl in 10 l water	1000 (980)#
Anonymous E	Benzalkonium chloride	5	1:10	5000 (4500)#
Anonymous F	Trichloroisocyanuric acid	50 - 100	Tablets	?
Anonymous G	Hexahydrotriazine	?	?	?
Anonymous H	Hydrogen peroxide	35	?	?
Anonymous I	Sodium hypochlorite	1 – 5	?	?
Anonymous J	5-bromo-5-nitro-1,3-dioxane	?	?	?

* Used in the reference scenario and based on Deltagraph (1997) and Cederquist (2004)

(Exact value)

To investigate how much the use of a biocide agent, registered at the Danish Ecolabelling Agency for preserving rinsing water (repro, plate making), may change the LCA profile of the reference scenario, rinsing water with 5000-ppm benzalkonium chloride is used in this scenario. To reflect to typical situation in Northern Europe, the fate in WWTP is included, i.e. only 10% of the benzalkonium emitted to the sewage system ends up in the water recipient after treatment in the WWTP (see Table 14)

2.4.7 Scenario 7: No waste water emitted

At least some Danish sheet fed printing companies emit no wastewater at all. Recycled rinsing water from the film developing may be used when replenishing the fixer and other wastewater may be collected and disposed of as chemical waste. In order to reflect this kind of situation, we use a scenario based on the reference scenario but with all water emissions at the production stage excluded. However LCA data on treatment of chemical waste is not readily available and it has not been possible within the scope of this study to include a separate study on the potential environmental impact of disposing of used rinsing water as chemical waste.

3 Impact assessment

3.1 Methodology

The impact assessment methodology used here is the one defined by the EDIP method (Wenzel, Hauschild and Alting 1997; Hauschild and Wenzel 1998). The impact categories included cover potential global impacts (global warming and ozone depletion), potential regional impacts (acidification, nutrient enrichment, photochemical ozone formation, chronic human toxicity via water and soil, and chronic ecotoxicity in water and soil) and potential local impacts (acute human toxicity via air, acute ecotoxicity in water, hazardous waste, nuclear waste, slag and ashes, and bulk waste. In addition, resource consumption (RC) is included. The resources are treated as the equivalent amount of pure raw material, e.g. pure copper.

The EDIP LCV tool version 3.11 Beta (Miljøstyrelsen 1999) is here used to perform the calculations in the different steps of the impact assessment described below, i.e. classification, characterisation, normalisation and weighting, but the modelling has been done in a spreadsheet model. In addition the impact assessment calculations have been controlled (spot tests and critical values) and supplemented by spreadsheet calculations especially for the chemical related impact categories

3.1.1 Classification

Emissions (or other exchanges) mapped in the inventory are assigned to the relevant impact categories, e.g. CO_2 and CH_4 emission are assigned to global warming potential (gwp) and the CH_4 emission is also assigned to photochemical ozone formation.

3.1.2 Characterisation

For each impact category, a category indicator result (EP) is calculated by summing up the results of each assigned emission quantity (Q) multiplied by its corresponding characterisation factor (EF) within that impact category:

$$EP_{\text{impact category A}} = Q_{1A} * EF_{1A} + Q_{2A} * EF_{2A} + \ldots\ldots\ldots\ldots$$

For example for global warming:

$$EP_{gwp} = Q_{CO2} * 1 + Q_{CH4} * 25 + \ldots\ldots\ldots\ldots$$

In this example EF_{CO2} has the value 1 g CO_2/g CO_2 and EF_{CH4} the value 25 g CO_2/g CH_4, so the resulting EP_{gwp} is given in the unit gram of CO_2. As is indicated by this example, all the characterisation factors for the emitted substances contributing to global warming are expressed in units of CO_2 equivalents. This is the reason why characterisation factors in the EDIP methodology are also called Equivalency Factors (EF). Furthermore, the category indicator result or impact potential is called Effect Potential (EP) in the EDIP methodology.

The category indicator results for all the impact categories included represent the characterised Life Cycle Impact Assessment (LCIA) profile of the generic printed matter. This profile can be presented as such, but here we have chosen to represent the profile as normalized values and as weighted values to assist comparisons across impact categories.

The Characterisation factors used in this study are taken from Wenzel, Hauschild and Alting (1997), Hauschild and Wenzel (1998), Miljøstyrelsen (1999, and a soon to be issued new version including factors for textile chemicals) and Larsen et al. (1999a, 1999b) or estimated as part of this study, see Section 3.2.1.

3.1.3 Normalisation

In order to provide an impression of the relative magnitude of the potential impacts and resource consumptions, the category indicator results can be related to reference information. In the EDIP method this reference information is represented by the total impact potential or resource consumption in the world divided by the number of world citizens. For example for global warming the reference information (normalisation reference (NR), designated ER_{90}) is 8,700 kg CO_2-equivalents/person/year, meaning that in 1990, greenhouse gases equivalent to 8,700 kg CO_2 was emitted to air on average for each citizen worldwide. Also for ozone depletion, and for all resource consumptions, the normalisation reference (for resources RR_{90}) is based on global values whereas for all other impact categories, the reference region is Denmark (Sweden for nuclear waste).

The normalized category indicators (NEP) and normalized resource consumptions (NRC) are calculated by dividing the category indicator result or resource consumption (RC) by the corresponding normalisation reference (EP/ER90 or RC/RR_{90}). The normalised results are thus expressed in units of person-equivalents (PE) or typically divided by 1000 and designated milliperson-equivalents (mPE_{WDK90} or mPE_{W90}). During normalisation in the EDIP method the category indicators for chronic toxicity, i.e. chronic ecotoxicity in water (etwc), chronic ecotoxicity in soil (etsc), chronic human toxicity via water (htwc) and chronic human toxicity via soil (htsc) are gathered in one aggregated average toxicity impact category called persistent toxicity (pt). In this way, the toxicity at a regional scale is gathered in one category: $NEP_{(pt)} = (NEP_{(etwc)} + NEP_{(etsc)} + NEP_{(htwc)} + NEP_{(htsc)})/4$. The category indicators for acute effects, i.e. acute ecotoxicity in water (etwa) and acute human toxicity via air (hta) are kept separate. Thus two acute toxicity related impact categories at the local scale are defined, i.e. one for acute ecotoxicity (et): NEP(et) = NEP(etwa), and one for acute human toxicity (ht): NEP(ht) = NEP(hta).

The normalisation references used in this study are taken from Wenzel, Hauschild and Alting (1997), Drivsholm et al. (1996) and Miljøstyrelsen (1999).

3.1.4 Weighting

By normalisation we arrived at the different potential impacts from the product system in question (i.e. the functional unit) related to the impacts from an average person in 1990. However, we have no indication of how serious the different normalized category indicator results are compared to one another. By introducing weighting factors (WF) we can achieve an indication of seriousness.

In the EDIP method, the weighting factors for the potential environmental impacts are based on political environmental targets and for the resource consumption they are based on the scarcity of the resource as expressed by the supply horizon. So the weighting factors for the individual impact categories are based on the Danish political targets for the reduction of impact within regional and local impact categories whereas weighting of the global impact categories is based on international conventions and plans of action for reduction. The reference year is 1990 and the target year is 2000 meaning that if the political target is to reduce the impact within a certain impact category by 50% during that period the weighting factor (WF) becomes 2 (100/50 = 2). The weighted normalized category indicator results (WEP) are calculated by multiplication: WEP = WF * EP, and expressed in targeted milliperson-equivalents ($mPET_{WDK2000}$). For normalized resource consumption the supply horizon for non-renewable resources is calculated by dividing the known reserves by the annual global consumption. The weighting factor is afterwards calculated as the reciprocal of the supply horizon. The normalized resource consumption is multiplied by the corresponding weighting factor giving rise to the weighted normalized resource consumption (WR) expressed in units of milliperson-reserves (mPR_{W90}).

By weighting we have the opportunity to aggregate the environmental impact category indicator results in one common impact score (unit: $mPET_{WDK2000}$) and the entire individual weighted normalized resource consumption in another common score (unit: mPR_{W90}).

The weighting factors used in this study are taken from Wenzel, Hauschild and Alting (1997), Drivsholm et al. (1996) and Miljøstyrelsen (1999).

3.2 Characterisation factors for the chemical-related impact categories

The impact categories on ecotoxicity and human toxicity differ from all the other impact categories because a very large number of chemical emissions may contribute to potential toxicological impact. Substances contributing to other impact categories such as global warming, nutrient enrichment and acidification (mainly energy-related impact categories) are limited in number and well defined, and characterisation factors are already available. However for the chemical-related impact categories covering ecotoxicity and human toxicity, a sufficient number of characterisation factors are not at all available to day to cover all the most important contributors. Furthermore many of the existing characterisation factors for the chemical related impact categories are based on poor data availability and/or poor data quality. In order to compensate for this application factors are used when characterisation factors are estimated. For example application factors between 10 and 1000 are used in the EDIP method when characterisation factors for chronic ecotoxicity are estimated. This estimation principle has the consequence that the value of the characterisation factor for a given substance may vary a factor of 10 or even 100 depending on the data available and used. The characterisation factors and the normalisation references for the chemical related impact categories should therefore be considered as having a higher uncertainty than those of the energy related impact categories.

In this study, we have tried to get a better coverage of the chemical-related impact categories than is typically the case in LCA studies by including characterisation factors from recent work in other industry sectors and by calculating new ones for chemical emissions expected to contribute significantly.

As is evident from the scoping and inventory (see Section 1.1.2 and 2.1- 2.3), the coverage of emissions from processes in the material stage and the disposal stage are far from as detailed as for the production stage (see Annex B), and specific chemical emissions are rarely known except for emissions of metals from electricity production, see Annex C.

In spite of the fact that the inventory of the production stage is much more detailed than that of the other stages (see Section 2 and Annex B), even the composition of the raw materials used during the production stage is based on simplifying assumptions, and some minor components have been excluded due to lack of data.

An overview of the emissions, for which characterisation factors for the chemical related impact categories are included in this study, is given in Annex C.

The total number of emissions to air included in this study is 99 (excluding emission of CO_2 and water) and compiled in Annex C. Among these, 33 emissions are covered by characterisation factors for human toxicity corresponding to 33% (33/99) and 26 are covered by characterisation factors for ecotoxicity corresponding to 26%. The emissions from the material stage and the disposal stage (mainly the former) include unspecific categories like VOC, NMVOC, unspecified dust for which more specific information of actual content is not available. 48% of the total emitted quantity (kg) is covered by characterisation factors for human toxicity and 21% for ecotoxicity part. If we exclude the amount coming from some of the highest contributing emissions (SO_2, NO_x, unspecified dust, COD, calcium, Cl^- and suspended solids), for which at least the main part typically does not contribute significantly to the potential ecotoxicity impact, the coverage becomes 64% for the ecotoxicity impact category.

The total number of emissions to water (103) included in this study is compiled in Annex C, except for 20 emissions from the production stage, covering substances for which the main part is assessed not to contribute significantly (see below) to the potential impact of the generic printed matter and therefore not included in the LCV-tool calculations, on which Annex C is based. 31 waterborne emissions are covered by characterisation factors for human toxicity corresponding to 25% (31/(103+20)) and 45 emissions are covered by characterisation factors for ecotoxicity corresponding to 37% of the total number.

The emissions from the material and disposal stage also include unspecific types like COD, TOC, VOC and suspended matter, for which information of the actual content is not available. Only 3.1% of the total emitted quantity (by weight) is covered by characterisation factors for human toxicity, and only 3.4% is covered for ecotoxicity. If we exclude the amount coming from the highest contributing emissions (SO_4^{--}, Tot-P, Na^+, COD, calcium, Cl^- and suspended solids), for which at least the main part typically does not contribute significantly to the toxicity impact categories, the coverage becomes 48% for human toxicity and 53% for the ecotoxicity part.

The main part of the specifically known individual emissions to water, which are not included (i.e. characterisation factors lacking), consists of inorganic salts (e.g. disodium silicate, sulphates), polymers (e.g. acrylates, modified phenol resin) and acids/bases (e.g. NaOH, HCl). In general, these substances/mixtures have a low toxicity and are not expected to contribute significantly to the toxicity impact categories, if not emitted in high quantities. In the latter case they will typically contribute only to acute ecotoxicity (e.g. reactive monomers from binders, acids or bases causing low or high pH), and only if not treated in a WWTP before emission to the water recipient. Most of them have been assessed in Larsen et al. (1995, 1998, 2000 and 2002) and Nielsen et al. (2000) for potential effects if emitted to WWTP or directly to water recipient on the basis of hazard assessments and/or generic risk assessments.

Known emissions from the production stage, which are not covered by characterisation factors, and which may contribute significantly to the toxicity impact categories, include emissions of components occurring in small quantities in the raw materials (typically well below 5%) like siccatives (organic metal compounds), softeners (phthalates), antioxidants (aromatics) and “wetteners” (surfactants). Due to lack of readily available knowledge of their exact identity and/or lack of readily available data on their inherent environmental properties it has not been possible to include them in this study.

From the material and the disposal stage, known emissions, which are not covered by characterisation factors but which may contribute significantly to the toxicity impact categories, include, for example, emissions of unspecified metals, AOX, unspecified oil and unspecified detergents.

3.2.1 New characterisation factors for ecotoxicity

Some of the substances emitted at the production stage are known to be very toxic and for others, the combination of moderate toxicity combined with a relatively large emitted amount may lead to significant contributions to potential impact. For some of these substances, characterisation factors did not exist in advance. Where relevant substance data have been available, characterisation factors have been calculated to fill this gap. As a special case, accumulated upstream characterisation factors representing the ecotoxicity of the total emissions to air, water and soil per gram produced from the production of the two pigments Pigment Yellow 14 and Pigment Blue 15, have been included (Andersen & Nikolajsen 2003). All the new characterisation factors made for this study are shown in Table 16.

Table 16. Characterisation factors estimated in this study and accumulated characterisation factors for pigments upstream.

CAS No.	Substance name	Characterisation factors (equivalency factors) (m^3/g)						
		Emissions to water			Emissions to soil		Emissions to air	
		$EF_{(etwa)w}$	$EF_{(etwc)w}$	$EF_{(etsc)w}$	$EF_{(etwc)s}$	$EF_{(etsc)s}$	$EF_{(etwc)a}$	$EF_{(etsc)a}$
147-14-8	Pigment Blue 15 *	1	1	0	0	0.000000033	0	0
2682-20-4	2-Methyl-4-isothiazolin-3-one (MI) *	200	1000	0	0	2070	0	0
26172-55-4	5-Chloro-2-Methyl-4-isothiazolin-3-one (CMI)*	455	4480	0	0	2560	0	0
123-31-9	Hydroquinone*	227	728	0	0	54.3	0	0
141-43-5	2-Aminoethanol*	0.667	1.33	0	0	3.16	0	0
56-81-5	Glycerol*	0.000185	0.00037	0	0	0.00086	0	0
28519-02-0	Benzenesulfonic acid, dodecyl(sulfophenoxy)-, disodium salt*	62.5	1160	0	0	0.0203	0	0
52-51-7	2-Bromo-2-nitropropane-1,3-diol (Bronopol)*	27	135	0	0	314	27	251
79-07-2	2-Chloroacetamide*	179	357	0	0	500	71.4	400
5468-75-7	Pigment Yellow 14 (u.s.)#	5.03	9.26	2.76	-	-	-	-
147-14-8	Pigment Blue 15 (u.s.)#	5.31	10.4	1.29	-	-	-	-

* Calculation of characterisation factors based on data from PhysProp (2004), ECOTOX (2004), ChemFate (2004), IUCLID (2000), Madsen et al. (2001), CERI (2004), Mackay et al. (2000), US-EPA (2004) and in some cases also including QSAR estimations on basis of EPIwin (2000).
# Accumulated upstream characterisation factors, i.e. summing up all potential impact from water, air and soil emission from the production process (synthesis) of the pigments (Andersen & Nikolajsen 2003).

As is evident from the characterisation factors in Table 16, the difference between the potential impacts differs widely between the substance emissions which have been included from the production stage. The relative difference between potential acute aquatic impact for substances with the least potential (represented by glycerol) and those with the highest (represented by CMI) is at the level of a factor 10^6. So to obtain the same potential impact for an emission of CMI and of glycerol, glycerol has to be emitted in a quantity that is more than a million times higher than the quantity of CMI.

The accumulated upstream characterisation factors for Pigment Blue 15 and Yellow 14 in Table 16 are not related directly to emissions, i.e. they are not to be multiplied by an emitted amount, as is the case for the other characterisation factors. Instead these accumulated characterisation factors are expressed per gram produced of the two pigments. The factors must therefore be multiplied by the consumption of the relevant pigments at the production stage (model printing company). The result represents the potential impact from the emissions during the production of the pigments (material stage). The emissions scenarios on which these upstream characterisation factors are based are taken from the EC Technical Guidance Document (TGD) on risk assessment (EC 2002). This kind of scenario is used for first tier risk assessment/screening and may therefore be conservative. However, Andersen & Nikolajsen (2003) have consistently used the lowest among the proposed values for emitted fraction in every case (produced amount > 2000 ton, assuming WWTP at the production facilities). The size of the characterisation factor for Pigment Yellow upstream is mainly determined by emission of 3,3-dichlorobenzidine and 2-chloroaniline during the synthesis of the pigment. For Pigment Blue 15 upstream, the main contributing emission is cuprous chloride (Andersen & Nikolajsen 2003).

3.3 Results of impact assessment: Reference scenario

The total inventory results divided into air emissions, water emissions, waste, and resources and materials are shown in Annex C. After classification and characterisation, these data can be presented as category indicator results as shown in Table 17.

Table 17. Category indicator results for the reference scenario

Name	Amount	Unit
Global warming	1,350,000	g CO_2-equiv.
Ozone depletion	0.0000106	g CFC11-equiv.
Acidification	4,000	g SO_2- equiv.
Photochemical ozone formation	1,560	g C_2H_4- equiv.
Nutrient enrichment	5,390	g NO_3- equiv.
Human TOX, water	1,540	m^3 water
Human TOX, air	38,800,000	m^3 air
Human TOX, soil	20.4	m^3 soil
EcoTOX, water, chronic	133,000	m^3 water
EcoTOX, water, acute	17,700	m^3 water
EcoTOX, soil	4,940	m^3 soil
Bulk waste	50,800	g
Hazardous waste	1,830	g
Radioactive waste	1.99	g
Slags and ashes	7,270	g
Primary energy, material	7,360	MJ
Primary energy, process	29,600	MJ
Al (aluminium)	317	g
Lignite	4,390	g
Chalk ($CaCO_3$)	64,600	g
Cr (chromium)	20.3	g
Cu (copper)	9.42	g
Fe (iron)	216	g
Ground water	1,470,000	g
Quartz	196	g
Clay	0.931	g
Mn (manganese)	3.74	g
Sodium chloride (NaCl)	15,600	g
Natural gas	306,000	g
Ni (nickel)	8.68	g
Dammed water	14,300,000	g
Surface water	30,100	g
Crude oil	125,000	g
Anthracite	7,240	g
Wood (soft) DS	941,000	g
Wood (hard) DS	0.183	g
U (Uranium)	1.57	g
Unspec. Fuel	-1,340	MJ
Unspec. water	46,000,000	g
Zn (zinc)	0.151	g
Hydrogen	3.69	g
Unspec. biomass	425	g
Kaolin	258,000	g
Bentonite	23.4	g
Ag (silver)	56.3	g

The category indicator results shown in Table 17 for the energy related impact categories (global warming, acidification and nutrient enrichment) are mainly due to emission appearing during energy production, especially for production of paper, but also from energy consumption at the model printing company. For the global warming potential, 72% is thus related to the paper production whereas 26% is related to the production stage (model printing company). If energy recovery from incineration and recycling of paper is allocated to the paper production, the figures change to 57% contribution to global warming from paper production and 39% contribution from energy consumption at the model printing company.

The category indicator result for stratospheric ozone depletion is dominated by emissions from energy production but insignificant.

The two main contributors to photochemical ozone formation are emissions of IPA and hexane from the production stage contributing with 45% and 19% respectively. The rest is dominated by the contribution from energy production-related VOC emissions.

The category indicator result for acute ecotoxicity in water is dominated by contributions from emissions of tetradecane (printing and cleaning at the production stage) and contribution from emissions of synthesis chemicals (e.g. 3,3-dichlorobenzidine) at the synthesis of pigments (material stage) contributing with 52% and 29% respectively. Emission of strontium related to energy production (especially for production of paper, heavy fuel oil for production of pulp) accounts for 10% and emission of biocides at the production stage accounts for about 5% (CMI dominating).

For chronic ecotoxicity in water, the main contributors include emissions of hexane occurring at the production stage (cleaning process) and emission of strontium related to the energy production. These two substances contribute 66% and 13% respectively. Contribution from emissions during the synthesis of pigments accounts for about 7% and emissions of biocides at the production stage about 6%.

The contributors to the category indicator for chronic ecotoxicity in soil are dominated by emissions during pigment synthesis, and emission of IPA and hexane during the printing process contributing with 39%, 32% and 29% respectively.

The emissions contributing most to human toxicity via air are energy production-related emissions, i.e. nitrogen oxides, NOx (69%) and sulphur dioxide (7%). Furthermore, emission of benzene related to the use “ekstraktions benzin” for cleaning at the production stage contributes about 10%, and emission of lead related to energy production 7%.

For chronic human toxicity via water, a lot of different emissions contribute. For example emissions of metals related to energy production, e.g. emission of mercury related to combustion of fuel oil contributes 26%. Also emissions from the production stage contribute, e.g. emission of hexane used in the cleaning process contributes 13%.

The category indicator result for chronic human toxicity via soil is dominated by contributions from emissions of IPA (47%) and benzene (24%) from the production process, i.e. printing and cleaning respectively. Energy related emissions also contribute, e.g. emission of vanadium with 5%.

The resource, which is consumed in highest amounts, is water (dam water, unspecified water and ground water) accounting for more than 50 tons of water per functional unit. The main part of the water is used for paper production directly (73%) and dam water for energy production about 22%. The second highest consumption is found for the group of energy carriers comprising natural gas, oil and wood accounting for about 1.4 tons per functional unit. The resource kaolin used as filler in the production of paper accounts for the third highest consumption, i.e. about 0.35 ton per functional unit.

3.3.1 Normalized reference scenario

The normalized LCA-profiles for the reference scenario are shown below and divided into profiles on potential environmental impact and profiles on resource consumption.

3.3.1.1 Potential environmental impact

In Figure 2 the results of the impact assessment of the reference scenario are shown as normalized values divided into the steps at the model printing company. Impacts related to energy consumption at the model printing company, water consumption at the model printing company, incineration of printed matter/paper waste, recovery due to recycling/incineration of paper, and paper production are isolated and shown separately. Avoided potential impacts due to recycling and incineration of paper are shown as negative values.

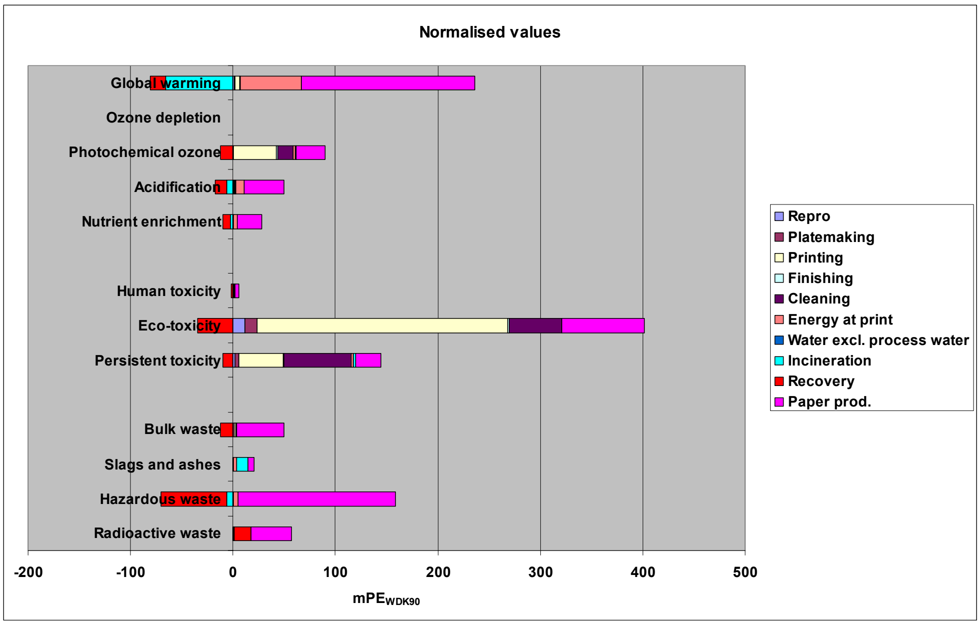


Figure 2. Normalized LCA profile for the reference scenario

As is evident from Figure 2 the dominating potential impact expressed in milliperson equivalents (mPE) is acute ecotoxicity accounting for about 400 mPE. For this category, the printing process accounts for more than half, i.e. about 240 mPE, and paper production contributes 80 mPE. In the same category cleaning contributes 51 mPE, plate making and repro 12 mPE each, whereas finishing and energy consumption at the model printing company only account for 1,4 mPE and 0.033 mPE respectively. Furthermore, recovery of paper contributes -35 mPE for the category for acute ecotoxicity due to avoided emissions from avoided paper production based on virgin fibres. For human toxicity (acute), the only contributions above 1 mPE come from paper production (3.5 mPE) and energy consumption at the model printing company (1.1 mPE). For persistent toxicity the main contributor is cleaning with about 66 mPE followed by printing (43 mPE) and paper production (24 mPE). For this impact category, plate making and repro only account for 4 mPE and 2 mPE respectively, and incineration of paper and energy consumption at the model printing company account for 2.6 mPE and 2.0 mPE respectively. Finishing only contributes 0.60 mPE and recovery of paper contributes -10 mPE.

The normalized global warming potential in Figure 2 accounts for almost 240 mPE, and paper production dominates this impact category with about 170 mPE, while energy used at the model printing company contributes 60 mPE. Printing, repro and plate making contributes 3.9 mPE, 1.5 mPE and 0.83 mPE respectively whereas finishing and cleaning only account for 0.62 mPE and 0.41 mPE. For global warming, incineration and recycling of paper save emissions equivalent to contributions of -66 mPE and -15 mPE respectively.

The normalised results for the impact category photochemical ozone formation in Figure 2 are dominated by printing, paper production and cleaning, contributing 42 mPE, 28 mPE and 15 mPE respectively. Energy consumption at the model printing company contributes 2.6 mPE whereas the contribution from repro, plate making, finishing and incineration of paper all lie below 1 mPE. Recycling of paper accounts for -12 mPE photochemical ozone formations.

Both normalized results for nutrient enrichment and acidification in Figure 2 are dominated by contributions from paper production and energy consumption at the model printing company. For nutrient enrichment, the contributions are 24 mPE (paper production) and 3.5 mPE (energy consumption), and for acidification 38 mPE (paper production) and 8.7 (energy consumption). All the other process steps at the model printing company contribute less than 1 mPE, except for printing, contributing 1.0 mPE to acidification. Contributions from incineration and recycling of paper to nutrient enrichment are -2.4 mPE and -7.9 mPE respectively and to acidification -6.0 mPE and -11 mPE respectively.

The dominating contributor to the formation of bulk waste, hazardous waste and radioactive waste is paper production, contributing 46 mPE, 154 mPE and 39 mPE respectively, see Figure 2. The only processes at the model printing company contributing more than 1 mPE are plate making and printing, and the contributions are only to the impact category for bulk waste (1.3 mPE and 1.2 mPE respectively). Incineration and recycling of paper contribute to bulk waste with -0.12 mPE and -12 mPE respectively, to hazardous waste with -6.0 mPE and -64 mPE respectively, and to radioactive waste with -0.45 mPE and 17 mPE. For the impact category for slag and ashes, only paper production (5.8 mPE), incineration (11 mPE) and energy consumption at the model printing company (2.5 mPE) contribute more than 1 mPE, see Figure 2.

The contributions from water consumption excluding process water, and ozone depletion in Figure 2 are not visible and insignificant. Water consumption excluding process water comprises the total water consumption per functional unit at the model printing company minus the water consumption in the repro, plate making, printing and cleaning process (i.e. the process water). Total water consumption is about 1200 litres per functional unit, and the process water consumption about 100 litres per functional unit. The contribution from the consumption of process water at the model printing company is thus also insignificant.

In order to illustrate the importance of paper for the normalised LCA profile of the reference scenario, a comparison of the total profile and a profile with paper excluded, i.e. paper production, recycling of paper and incineration excluded, is shown in Figure 3. For the total profile in Figure 3 (“total”) the avoided impacts (i.e. negative contributions) due to incineration and recycling of paper are allocated to paper, i.e. the paper net value is used.

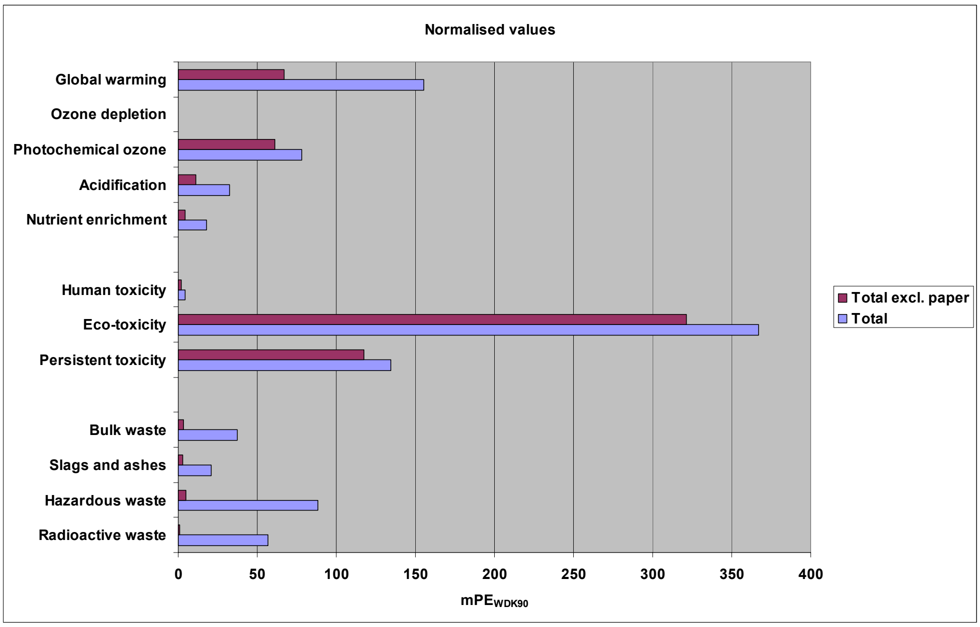


Figure 3. Normalized LCA profile of reference scenario comparing total (for paper the net value is used) with total excluding paper

Comparison of the two bar diagrams in Figure 3 reveals that about 67 mPE (43%) of the total normalized potential environmental impact for global warming is not related to the consumption of paper. Furthermore, paper plays only a minor role in the impact categories on acute ecotoxicity and persistent toxicity and contributes only moderately to photochemical ozone formation. On the other, hand paper is dominant in the categories for nutrient enrichment, acidification and the four categories for waste.

3.3.1.2 Resource consumption

The normalized profile for resource consumption is shown in Figure 4. Water and wood, which are the resources consumed in the highest amounts (see Table 17), are not included in Figure 4 because they are considered as renewable resources used at a rate which is lower than their current rate of regeneration. Chalk ($CaCO_3$) which is used in significant amounts (see Table 17), primarily as filler during recycling of paper, is also omitted from Figure 4 due to lack of a normalisation reference and to the assumption that it is insignificant as compared to the other resource consumption when we take existing reserves into account. The same goes for sodium chloride. Also the relatively small consumption of quartz and unspecified biomass, and the very small consumption of hydrogen and clay are omitted in Figure 4 due to lack of normalisation references and assumed unimportance. When no normalisation references exist in EDIP97 (Wenzel, Hauschild and Alting 1997) for these resources, it is indeed because the reserves are enormous compared to the current rate of extraction. Their supply horizon is thus very long which results in very low weighting factors meaning that the consumption of these resources is insignificant from a resource availability point of view. Normalized consumptions of manganese, iron and zinc are not shown in Figure 4 because they are very small, i.e. 2.1 mPE, 2.2 mPE and 0.11 mPE respectively. Silver is not included here due to lack of a normalisation reference. However, silver is included in the weighting step (see Section 3.1.2.2) because a factor for the combined normalisation and weighting (1/personreserve) exists for this resource, making normalisation and weighting possible in one step.

The normalized resource consumptions shown in Figure 4 are heavily dominated by consumption of kaolin during the production of paper, accounting for about 111000 mPE gross and 75300 mPE net (corrected for avoided consumption after recovery of paper). However, as pointed out by Drivsholm et al. (1997), kaolin may easily be substituted by chalk and talc for which the world consumption is several orders of magnitude higher than that of kaolin, e.g. world consumption of talc is a factor of 330 higher than that of kaolin (Drivsholm et al, 1996). So if the filler kaolin is substituted by talc and/or chalk the normalized value will be reduces by several orders of magnitude.

The second highest normalized resource consumption is for the energy resource natural gas, accounting for around 1570 mPE gross and 988 mPE net dominated by consumption during paper production (967 mPE gross and 390 mPE net) and consumption at the model printing company (452 mPE). Recycling of paper (recovery) and energy consumption for producing raw materials for the printing step (printing) account for smaller parts, i.e. 90 mPE and 40 mPE respectively. Finally, consumption of natural gas for producing raw materials for repro, plate making, cleaning and finishing only accounts for minor amounts, i.e. 2.25 mPE, 3.34 mPE, 2.21 mPE and 6.25 mPE respectively, and consumption for producing water excl. process water is negligible (0.07 mPE).

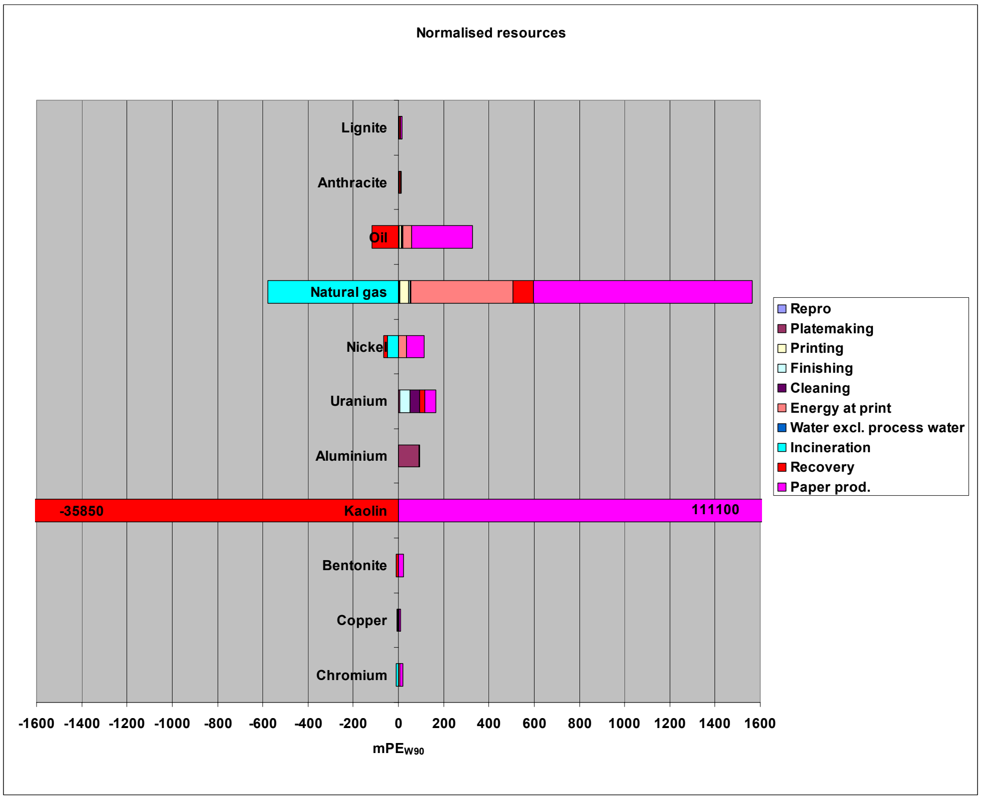


Figure 4. Normalized profile for resource consumption

The normalized consumption of oil is third in size and accounts for 327 mPE gross and 212 mPE net. The highest consumption is during paper production accounting for 270-mPE gross and 155 mPE net. Oil consumption for energy production at the model printing company accounts for 38.6 mPE and consumption for producing raw materials for repro, plate making, cleaning and finishing accounts for 1.29 mPE, 0.958 mPE, 3.36 mPE and 2.75 mPE respectively. Consumption for producing water excl. process water is negligible (0.00002 mPE).

For uranium, the normalized consumption accounts for 166 mPE gross and 165 mPE net. The main consumptions are in the paper production (48.9 mPE gross and 47.9 mPE net), finishing (44.7 mPE) and cleaning (44.0 mPE). Recycling of paper (recovery) and plate making accounts for 21.0 mPE and 4.54 mPE whereas repro, printing, energy at print and water excl. process water all account for less than 1 mPE.

The normalized consumption of the two last energy resources, i.e. anthracite and lignite, are very small compared to the results for natural gas and oil. Consumption of anthracite only accounts for 13.1 mPE gross (12.7 mPE net) and lignite only 17.6 mPE both gross and net. For both, the main consumption is for energy production during paper production and recycling of paper (recovery) accounting for 4.64 mPE and 4.64 mPE respectively for anthracite and 6.77 mPE and 7.60 mPE respectively for lignite. The process steps at the model printing company, energy consumption at the model printing company and water consumption except process water all account for less than 1 mPE except for plate making, accounting for 2.52 mPE (lignite), printing 1.18 mPE (anthracite) and finishing 1.14 mPE (anthracite).

For the consumption of the heavy metals nickel, chromium and copper, the normalised consumptions account for 114 mPE gross (48.2 mPE net), 19.7 mPE gross (8.37 mPE net) and 11.3 mPE gross (5.54 mPE net) respectively. The main consumptions of nickel are in the paper production (76.8 mPE gross, 11.4 mPE net) and the energy consumption at the model printing company (35.2 mPE). All other consumptions are below 1 mPE except for printing, consuming 1.52 mPE. For chromium, the picture is almost the same as for nickel, i.e. main consumptions are in paper production (13.3 mPE gross, 1.96 mPE net) and the energy consumption at the model printing company (6.10 mPE), but in this case all other consumptions are below 0.1 mPE except for printing consuming 0.263 mPE. Consumption of copper is slightly different than the consumption of nickel and chromium. The main consumptions are in paper production (6.83 mPE gross, 1.02 mPE net) and the energy consumption at the model printing company (3.13 mPE) but consumption in plate making is 1.25 mPE and in printing 0.135 mPE. All other consumptions of copper are below 0.01 mPE. This almost identical picture for consumption of nickel, chromium and copper illustrates that consumption of these heavy metals is highly connected to energy production.

The normalized consumption of bentonite is only significant for paper production accounting for 33.8-mPE gross and 13.1 mPE net.

In Figure 5, a normalized resource consumption profile is shown where paper (production, recycling and incineration) is excluded, making the resource consumption of the other processes more visible.

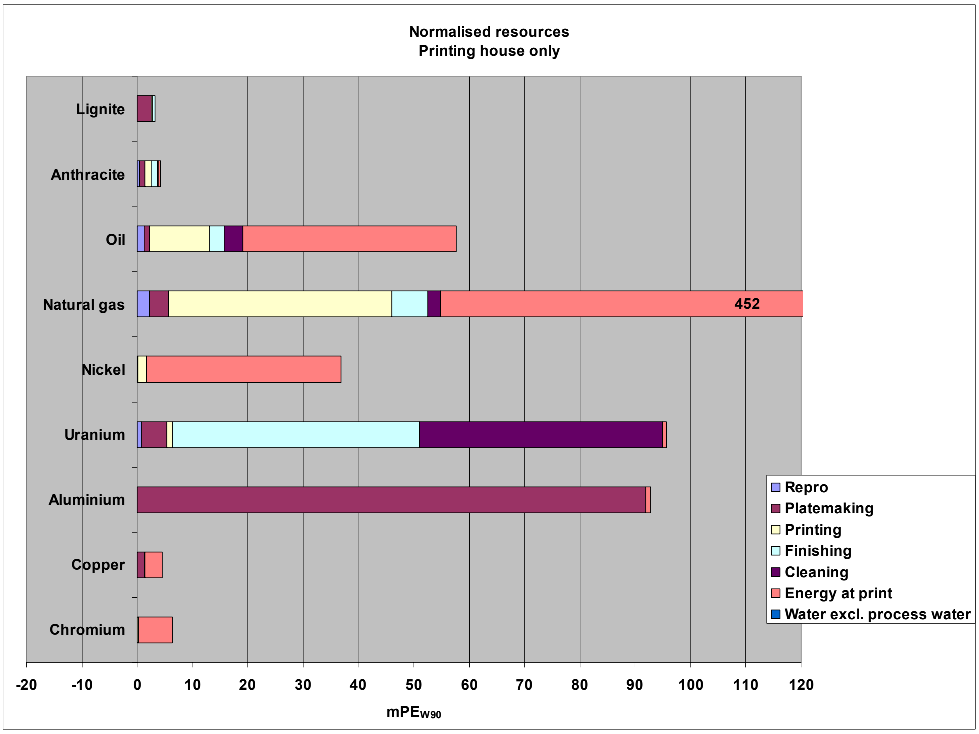


Figure 5. Normalized profile for resource consumption excluding paper

3.3.2 Weighted reference scenario

The weighted LCA-profiles for the reference scenario are shown below and divided into profiles on potential environmental impact and profiles on resource consumption.

3.3.2.1 Potential environmental impact

A profile for the weighted reference scenario is shown in Figure 6. By weighting the normalised LCA profile for the reference scenario, the dominating role of the chemical related impact categories is further strengthened. When compared to the normalized profile (see Figure 2), the main difference is that the dominant impact category for acute ecotoxicity is a factor of 2.3 higher (weighting factor, WF = 2.3) and for persistent toxicity a factor of 2.5 higher making this impact category the second highest in the weighted profile. Even though the normalized potential impact for human toxicity is multiplied by a WF of 2.8 during weighting, this impact category remains of minor importance in Figure 6. The normalized potential impact for global warming and acidification are both only multiplied by WF of 1.3 and for photochemical ozone formation and nutrient enrichment by a WF of 1.2 during the weighting process, and therefore these impact categories only undergo minor increments.

The impact categories for waste are all only multiplied by a WF of 1.1 and therefore only increase 10% when the normalized values are weighted. Even though the normalized potential impact from ozone depletion is multiplied by a WF of 23 during weighting, this impact category remains insignificant.

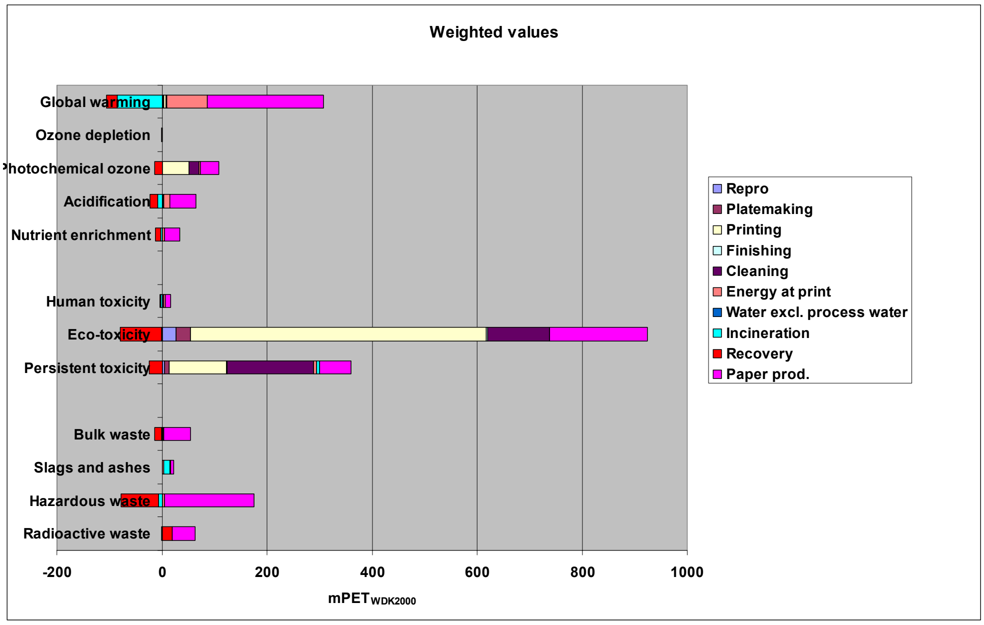


Figure 6. Weighted profile for reference scenario

By weighting we have the opportunity to aggregate all the environmental impact category indicator results in Figure 6 by summing them into one common impact score as mentioned in Section 3.1.4. By doing that we arrive at the summed profile for one functional unit expressed in units of weighted (targeted) milliperson equivalents (mPET) as shown for the individual processes in Figure 7.

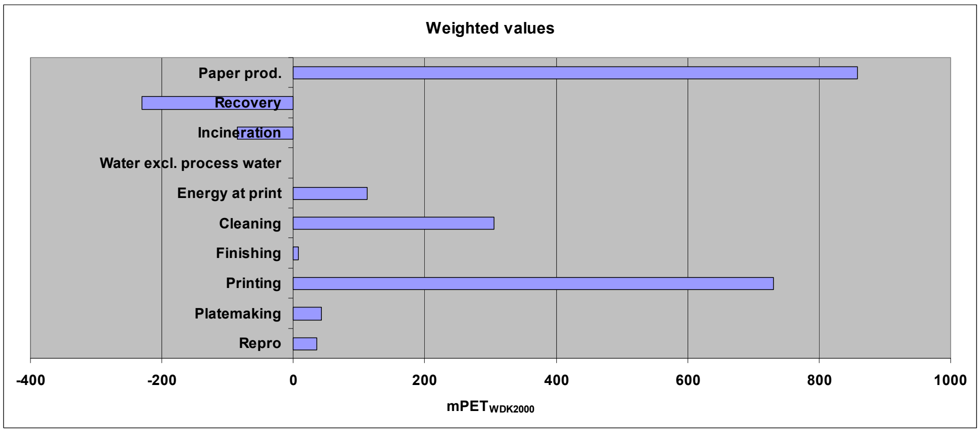


Figure 7. Aggregated weighted LCA profile for the reference scenario

Instead of showing the aggregated profile in absolute values as in Figure 7 we may use relative values as shown in Figure 8.

The results in Figures 7 and 8 show that for the aggregated weighted potential environmental impact (termed "aggregated impact" further on in this report), the production of paper is dominant with a contribution of 48% (gross) of the total whereas printing contributes 41%. Cleaning is third highest with a contribution of 17% and energy consumption at the model printing company, plate making and repro contributes 6%, 2% and 2% respectively. Finishing only contributes with 0.4% and water exclusive of process water only 0.001% (excluded in the further assessment).

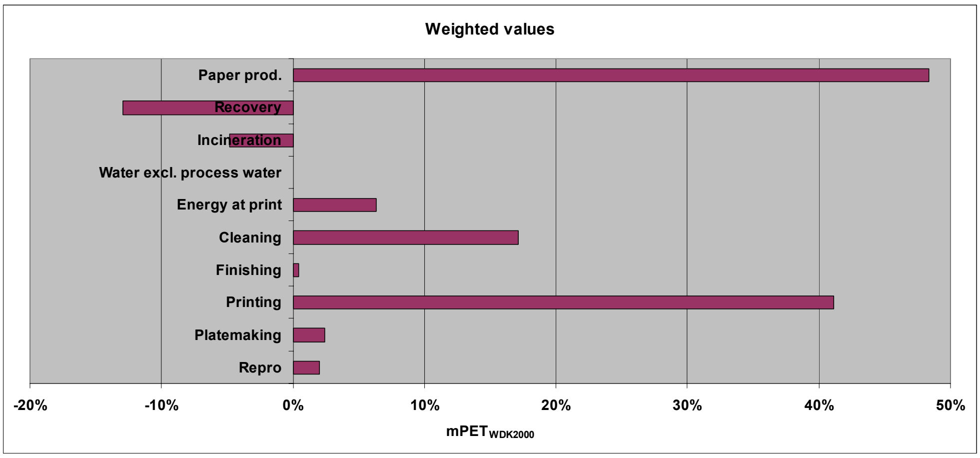


Figure 8. Aggregated weighted LCA profile for the reference scenario in relative figures.

Recycling of paper (recovery) and incineration contribute -13% and -5% respectively of the total in Figures 7 and 8. If we allocate these negative contributions to paper production (avoided emissions due to avoided paper production and avoided incineration of natural gas), we arrive at the profile shown in Figure 9. This profile shows that if paper is recycled at the rate defined by the reference scenario (53%), and the rest incinerated and the heat utilised, the paper production (total paper net value) only accounts for 31%, whereas the printing process now accounts for 41% of the aggregated impact. Cleaning and energy for print now account for 17% and 6% respectively, whereas plate making, repro and finishing account for 2%, 2% and 0.4% respectively.

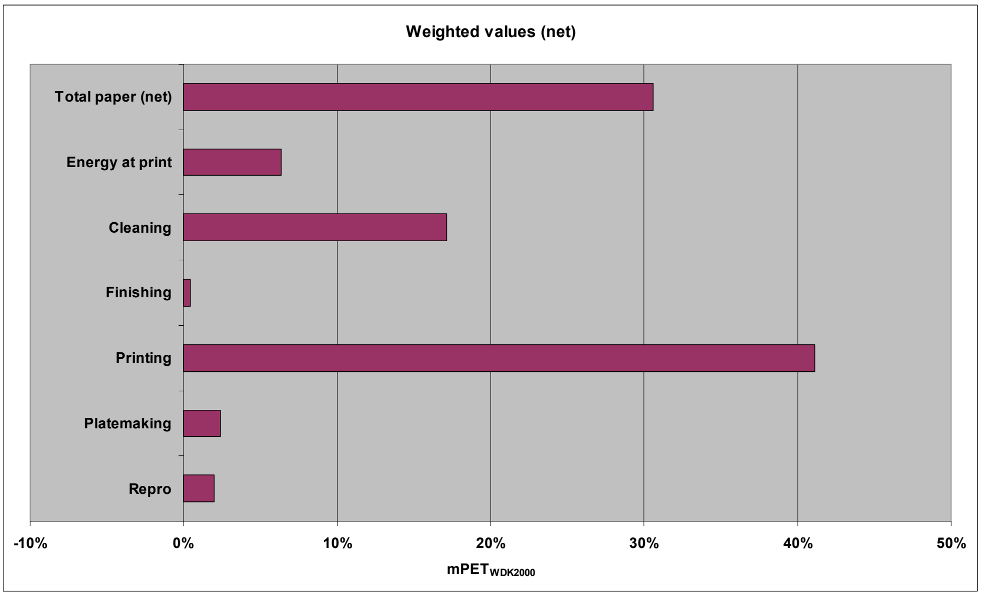


Figure 9. Aggregated weighted LCA profile for the reference scenario in relative figures and with total paper as net value.

Besides production of paper, the production of printing ink, which is another upstream production process in the life cycle of sheet fed offset printed matter, also contributes significantly to the aggregated impact. In Figure 10, ink production is isolated from the printing process and shown as a separate activity. As is evident from Figure 10 ink production contributes around 17%.

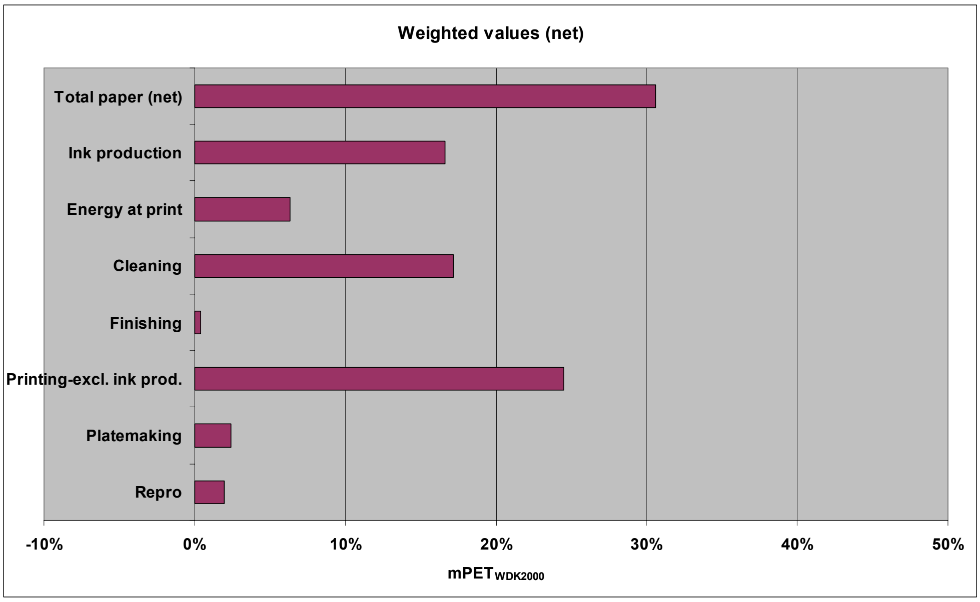


Figure 10. Aggregated weighted LCA profile for the reference scenario with ink production as separate category.

The reason for looking separately at paper here is its relatively dominant position. However it may be argued that paper is part of the printing process and should be allocated to printing as all the other raw materials are allocated to the corresponding process steps at the model printing company. If we do that, the printing process accounts for 72% of the aggregated impact. This leaves us with the total energy consumption at the model printing company (energy at print) as the only category in Figure 9 not distributed to the different process steps at the model printing company. If we assume that all energy consumption except electricity is used for heating and we use the energy data from Table 12 (Section 2.2) and the emission data on global warming (CO_2-eqv. emission) from the LCV database (Miljøstyrelsen 1999) it may be estimated that about 20% of the potential global warming from the energy consumption at the model printing company is related to heating. For the consumption of electricity it may be assumed on the basis of general data for the printing industry, i.e. not only offset (GA/DDF 2002), that illumination accounts for 15%, ventilation 20%, electronic equipment (computers etc.) 15% and other electric motors 35%. The rest is distributed among refrigeration (5%), compressed air (5%), heating (4%) and pumps (1%). As global warming is a dominant impact category for energy production, we may assume that it can serve as an indicator for the total potential impact in this case. If we further assume as a very rough estimate, that contributions from “other electric motors” can be allocated to the printing process (primarily printing machines etc.), that contributions from “electronic equipment” can be allocated to the repro process (dominated by electronic equipment), and that all other contributions can be allocated evenly to the five process steps at the model printing company we end up with a profile as shown in Table 18

Table 18. Relative contribution to the total aggregated weighted potential environmental impact from the different process steps at the model printing company (in percentage of total)

Process step at model printing company	Relative contribution to the aggregated impact (%)
Repro	4
Plate making	3
Printing	74
Cleaning	18
Finishing	1

3.3.2.2 Resource consumption

A weighted profile for resource consumption of the reference scenario is shown in Figure 11. If we compare this profile with the normalized profile (see Figure 4) we notice that consumption of kaolin is still dominant (141 mPR gross and 95.5 mPR net) but consumption of natural gas has gained importance in comparison to consumption of kaolin (25.0 mPR gross and 15.8 mPR net). This is also the case for oil (7.52 mPR gross and 4.87 mPR net) and uranium (3.03 mPR gross and 3.01 mPR net). The weighted consumptions of lignite (0.0457 mPR gross and net) and anthracite (0.0762 mPR gross and 0.0736 mPR net), though both still very small, have also become a bit more important as compared to their importance in the normalized profile. After weighting the consumption of bentonite (0.0262 mPR net) is still very small as when normalized, see Figure 11 and 4.

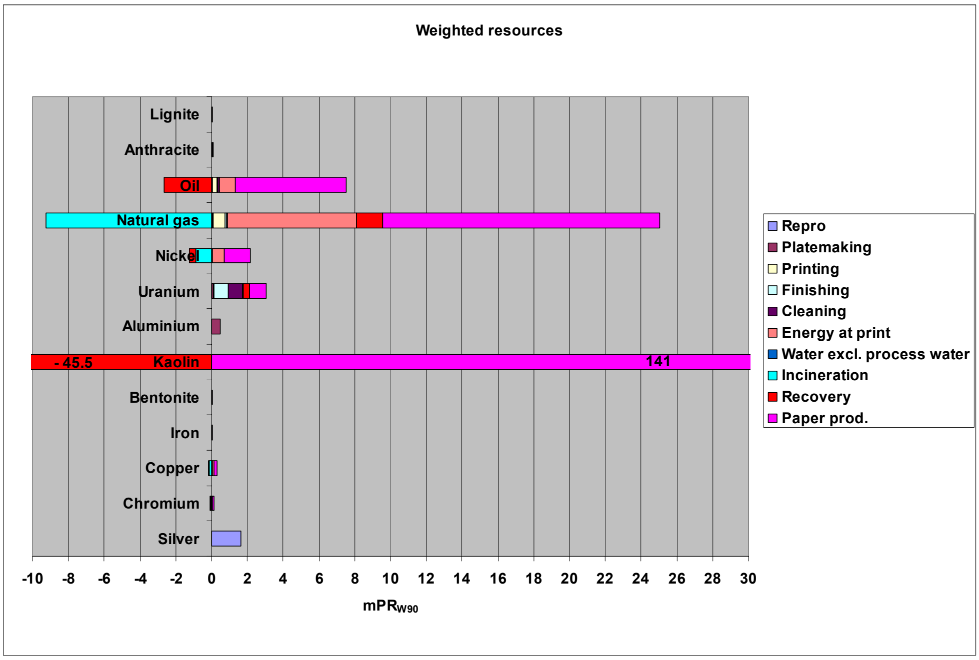


Figure 11. Weighted profile for resource consumption

The weighting factors for the metals nickel, aluminium, copper and chromium are all a bit higher (a factor of 4 – 22) than that of kaolin, and these metals therefore gain importance in the weighted profile, see Figure 11. Weighted consumption of nickel is highest with 2.16 mPR gross and 0.916 mPR net whereas aluminium accounts for 0.475 mPR. Copper and chromium only account for 0.318 mPR gross (0.155 mPR net) and 0.121 mPR gross (0.0512 mPR net). Iron only accounts for 0.0326 mPR gross (0.0184 mPR net).

As mentioned in Section 3.3.1.2 it is not possible to express consumption of silver as a normalized value, only as a weighted value as shown in Figure 11. Weighted consumption of silver accounts for 1.66 mPR.

In Figure 12, a weighted resource consumption profile is shown, where paper (production, recycling and incineration) is excluded, making the resource consumption of the other processes more visible.

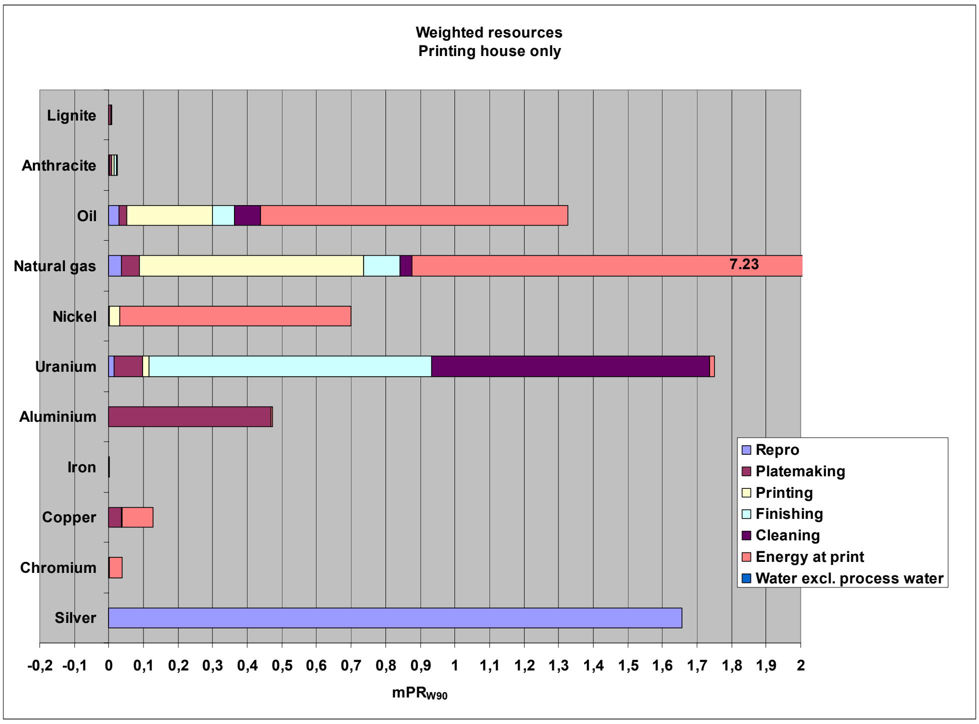


Figure 12. Weighted profile for resource consumption excluding paper

If we aggregate all the weighted resource consumptions in Figure 11 by summing them into one common resource consumption score, we arrive at the profile shown in Figure 13. Furthermore, if we express this aggregated profile in relative values instead of absolute values, we find the profile shown in Figure 14 and if paper is expressed in net values (total paper net) the profile shown in Figure 15.

As is evident from Figures 13, 14 and 15, production of paper is the overall dominating factor accounting for 135% gross and 88% net of the total aggregated weighted resource consumption. The second highest is energy consumption at the model printing company accounting for 7%, whereas all the other categories only account for 1%, see Figure 15.

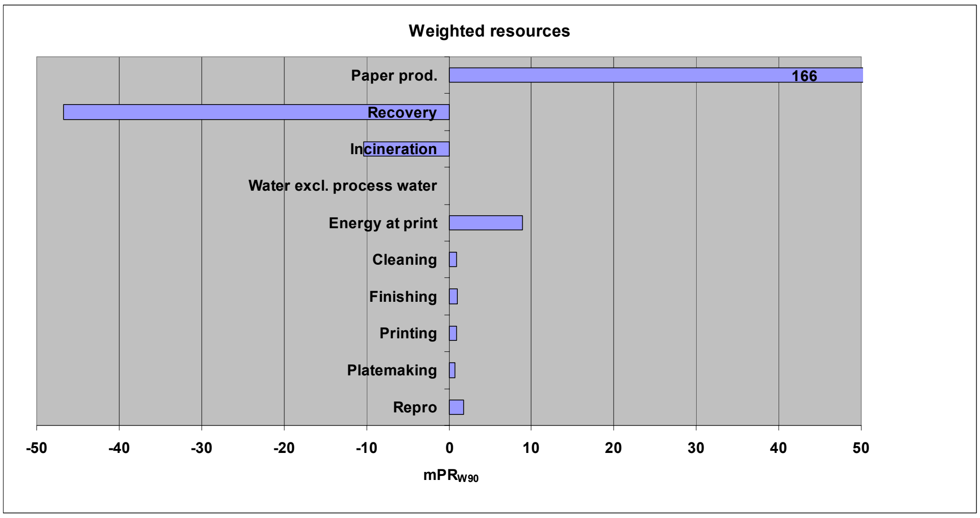


Figure 13. Aggregated weighted resource profile for the reference scenario

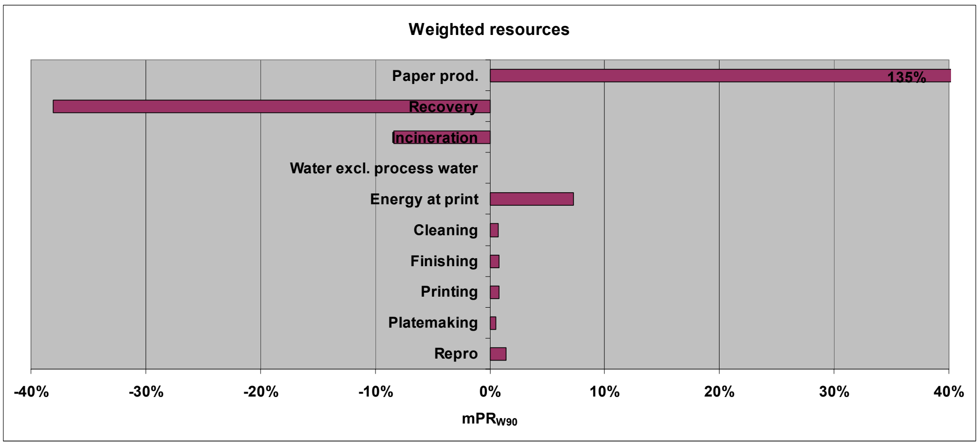


Figure 14. Aggregated weighted resource profile for the reference scenario in relative figures.

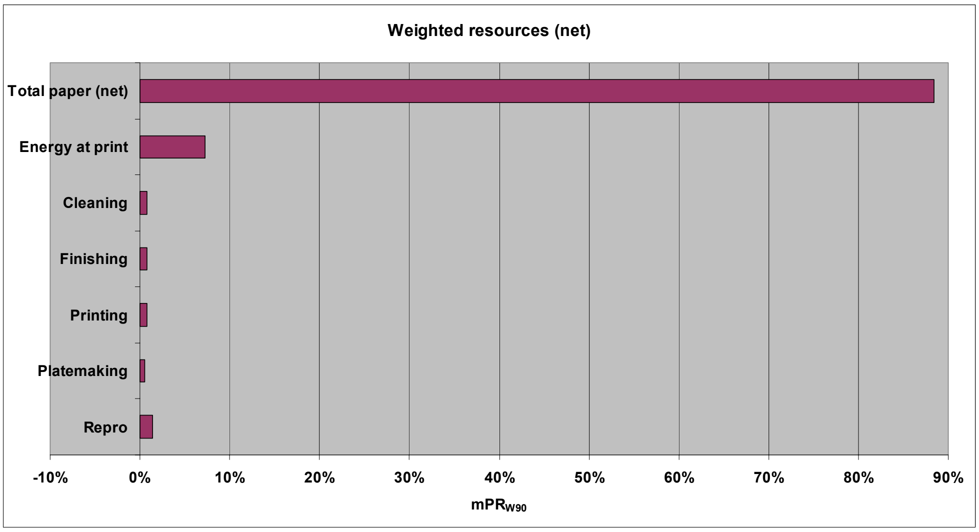


Figure 15. Aggregated weighted resource profile for the reference scenario in relative figures and with total paper as net value.

As pointed out in Section 3.3.1.2, kaolin may be substituted by talc and/or chalk for which the world consumption is several orders of magnitude higher and the supply horizon at the same level (Drivsholm et al. 1997). We may therefore present the aggregated weighted resource profile without kaolin as shown in Figure 16. In this case the paper production share of the total aggregated weighted resource consumption is reduced to 48% whereas energy consumption at the model printing company now accounts for 33%. Repro accounts for 6% and finishing and printing account for 4% each. Cleaning and plate making account for 3% and 2% respectively.

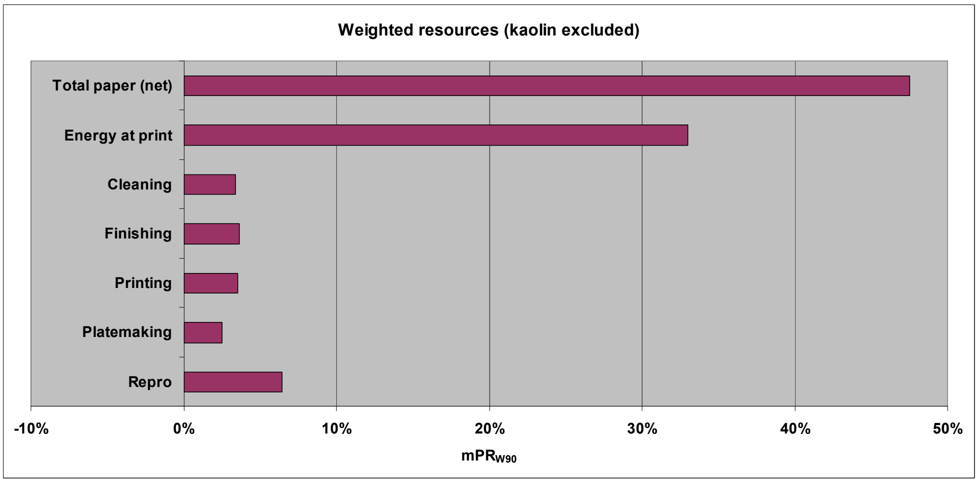


Figure 16. Aggregated weighted resource profile for the reference scenario in relative figures and with total paper as net value and kaolin excluded.

If we exclude paper totally we arrive at the profile shown in Figure 17. Now energy for print accounts for 63% of the total aggregated weighted resource consumption and repro accounts for 12%. Finishing and printing account for 7% each and cleaning and plate making for 6% and 5% respectively.

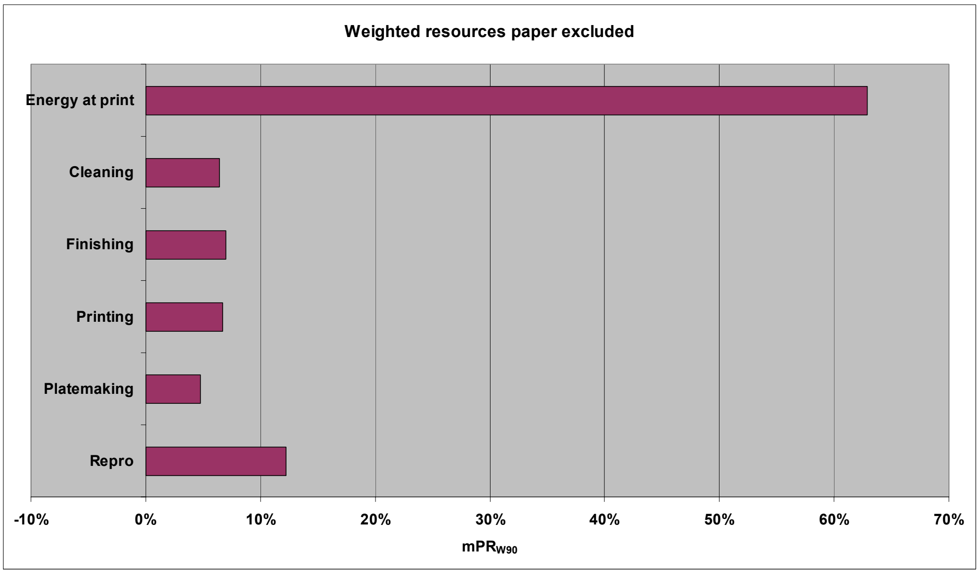


Figure 17. Aggregated weighted resource profile for the reference scenario in relative figures and with paper excluded.

3.4 Results of impact assessment: Average energy (scenario 1)

As mentioned in Section 2.4.1, the purpose of making a scenario based on average energy is to make it possible to compare the main results of our study with a previous LCA study of offset printed matter. The comparison is described below in Section 3.4.1.

The normalized profiles for scenario 1 are shown in Figures 18 and 19.

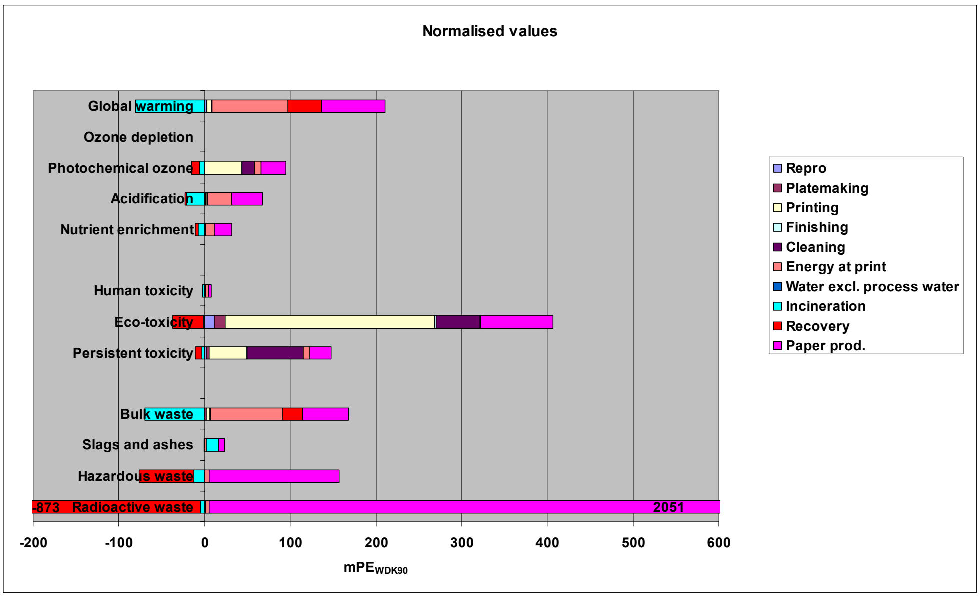


Figure 18. Normalized LCA profile for the scenario 1 (average energy based)

If we compare the environmental impact profile of scenario 1 in Figure 18 with the corresponding for the reference scenario (Figure 2) the main difference is the overall dominating role of radioactive waste in the profile for scenario 1, which is only of moderate significance in the reference scenario. Furthermore, bulk waste is about twice as large in scenario 1 as compared to the reference scenario.

These effects on the LCA profile due to the differences in energy scenario used (average instead of marginal) are also reflected in the resource profile shown in Figure 19. If we compare with Figure 4, the main differences are that consumption of uranium is now second most important, anthracite third most important (gross value) and natural gas only fourth most important.

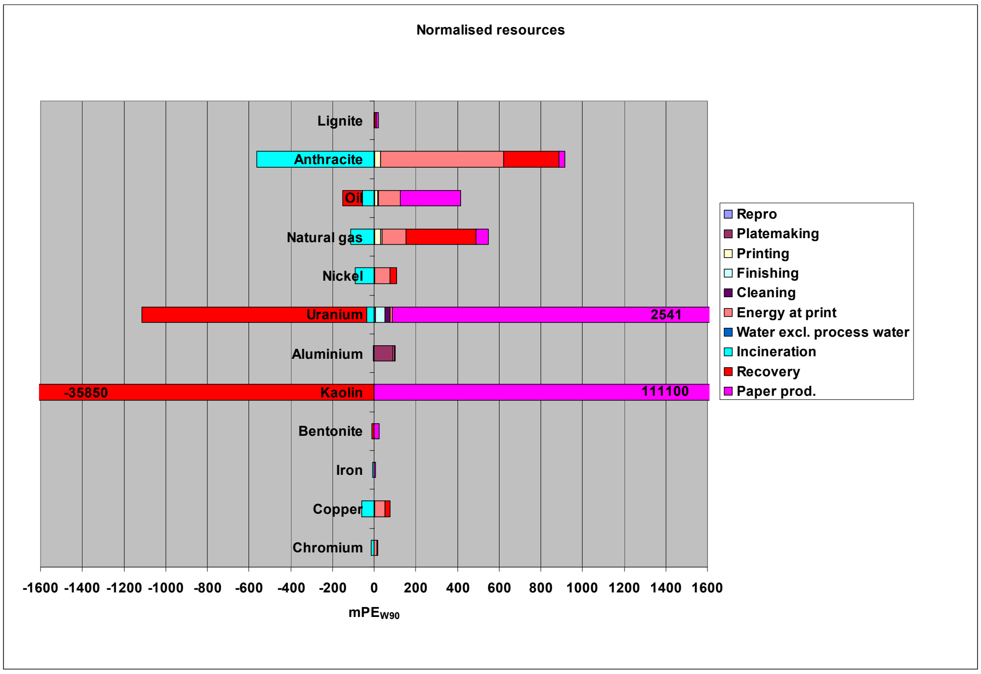


Figure 19. Normalized profile for resource consumption for scenario 1

3.4.1 Comparison with other LCA studies on printed matter

One of the LCA studies on offset printed matter (Drivsholm et al. 1996, 1997), which was mentioned in the Introduction, was performed using the same LCA methodology as this study, making a comparison meaningful. The goal of the study by Drivsholm and colleagues was among other things to create LCA profiles for three types of printed matter, i.e. a newspaper (cold-set), a weekly magazine (publication gravure) and a commercial (heat-set), and to identify the most important emissions and resource consumptions with the aim of identifying areas of intervention for reduction of potential environmental impact and resource depletion. Two of the products included are produced by use of offset technique but none by sheet fed offset. In the study by Drivsholm and colleagues, repro is excluded, and transport is fully included as an integrated part. The electricity scenario used by Drivsholm and colleagues is average (Swedish average for paper production) and for the comparison with this study, scenario 1 is therefore used.

In Figure 20 and Figure 21 the normalized profiles for scenario 1 are compared with the normalized profiles of the newspaper and the commercial. In all cases, the same type of overall functional unit is used (i.e. per tons product) and the same normalisation references are used.

Despite the fact that different types of offset printing techniques are used for cold set (rotation), heat-set (rotation, heat drying) and sheet fed offset (sheets), and to a certain degree different raw materials, e.g. paper for cold set (newspaper) contains wood fibres (i.e. produced from mechanical pulp) as opposed to graphic paper (white paper based on chemical pulp with a higher energy demand) included in the two other techniques, the difference between the profiles is not very large (see Figure 20 and Figure 21) with some exceptions commented on below.

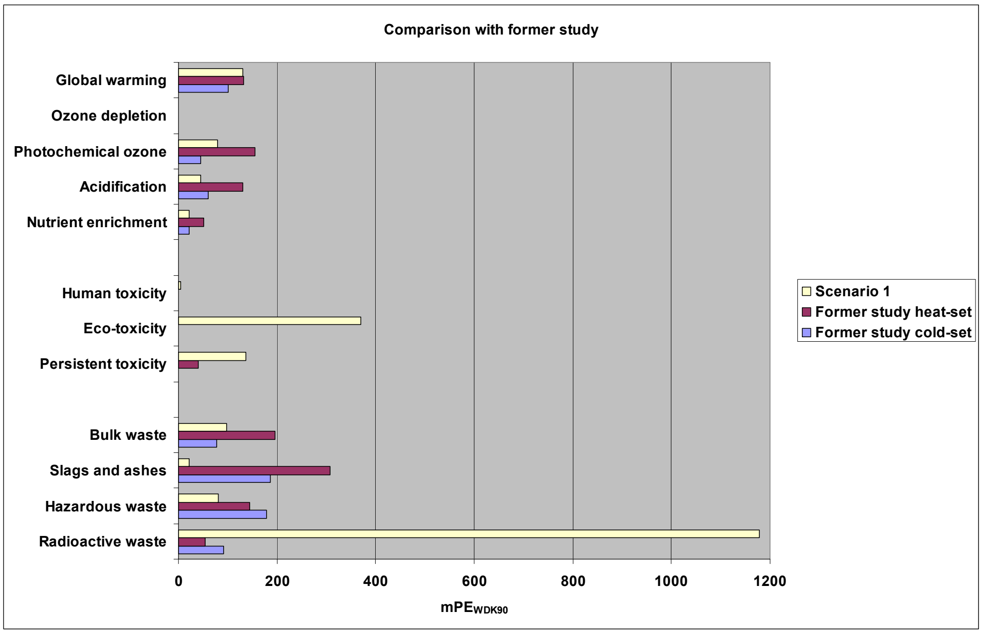


Fig. 20. Comparison of scenario 1 with a previous study by Drivsholm et al. (1996, 1997) on a newspaper (previous study cold-set) and a commercial (previous study heat-set).

As can be seen in Figure 20, the result of this study is at the same level for the energy related impact categories as the results from the previous study by Drivsholm et al. (1996, 1997) based on specific data from two specific Danish printing companies. The observed differences are probably mainly due to differences in the total energy consumption (primary energy, process) used per tons produced printed matter (energy consumption for producing thermo mechanical pulp (TMP) used for newspapers is lower than for producing sulphate pulp (INFRAS 1998) used for sheet fed offset paper). Furthermore, as indicated in Figure 21 there seem to be differences in, for example, the site specific energy scenarios used for the model printing company etc. (anthracite and natural gas instead of lignite and oil). The total energy consumption for the commercial is 43 GJ/ton and for the newspaper 33 GJ/ton (Drivsholm et al. 1996), whereas for scenario 1 it is 34 GJ/ton. Furthermore, as indicated in Figure 21, the energy resources for the newspaper and the commercial are dominated by anthracite, oil and natural gas in descending order, whereas scenario 1 is dominated by oil, lignite and anthracite in descending order.

The reason why photochemical ozone formation from the previous study on a commercial (heat-set) is about twice as high as that of scenario 1 is probably mainly that a much higher (factor 5) VOC emission per ton produced paper is assumed (data from a specific paper mill) which is partly compensated for by a higher VOC emission during printing and cleaning in scenario 1.

For bulk waste and hazardous waste, the results of the impact assessments for scenario 1 and the former study by Drivsholm et al. (1996, 1997) are at the same level as shown in Figure 20. However, the huge difference between the results on slag and ashes cannot be explained by differences in energy consumption or differences in overall energy scenario used but must be due to differences in the data used, i.e. amount of waste created per unit of energy produced.

The huge difference between the amounts of radioactive waste created per tons printed matter as depicted in Figure 20 is, as can be seen from Figure 21, not due to big differences in the amount of uranium used. The reason is a large difference in the data used for the amount of radioactive waste created for every unit of uranium used.

Only in the previous study on heat-set are chemical emissions included, and only a single one, i.e. IPA. The effect of including chemical emissions to a much higher degree and thereby taking impact categories for human toxicity and ecotoxicity into account (as in this study) is evident from the comparison shown in Figure 20 (persistent toxicity and especially ecotoxicity).

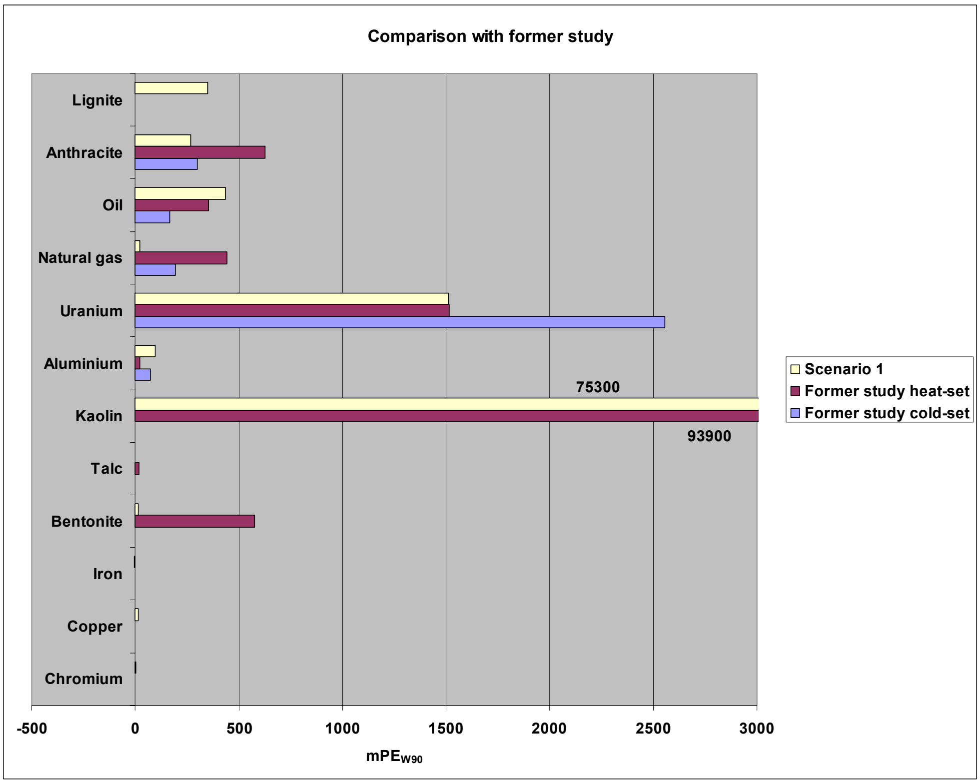


Fig. 21. Comparison of scenario 1 with a previous study by Drivsholm et al. (1996, 1997) on a newspaper (previous study cold-set) and a commercial (previous study heat-set).

The comparison in Figure 21 regarding the energy related resources is commented upon above. For the filler material kaolin, the consumption for one ton of commercials is at the same level as the consumption for one ton of product in scenario 1 (kaolin is not used in paper for newspaper production). However, consumption of bentonite is about a factor of 40 higher for the commercial than for the generic sheet fed printed matter in scenario 1. This may be due to differences in the filler combination used in the two studies and the fact that surface treatment of paper is not included in scenario 1.

For the metals, aluminium consumption is at the same level in the three cases (see Figure 21). Copper is 15 mPE for scenario 1 and zero for both the newspaper and the commercial. Iron and chromium are below 4 mPE in scenario 1 and also zero for both the newspaper and the commercial.

3.5 Results of impact assessment: Saturated paper market (scenario 2)

The result of comparing the reference scenario with a scenario where it is assumed that the paper market is saturated, and that the generic printed matter is produced on the basis of recycled paper exclusively, is shown in Figure 22. Increase in the normalized potential environmental impact is indicated in all impact categories, except for radioactive waste and “slag and ashes”, when changing the paper raw material from virgin to recycled. The main reason for the higher contributions from these two waste categories is that an average Danish energy scenario is used for recycling (not marginal and including different sources, e.g. nuclear energy and anthracite based energy) while for virgin paper production, natural gas based energy is used (marginal).

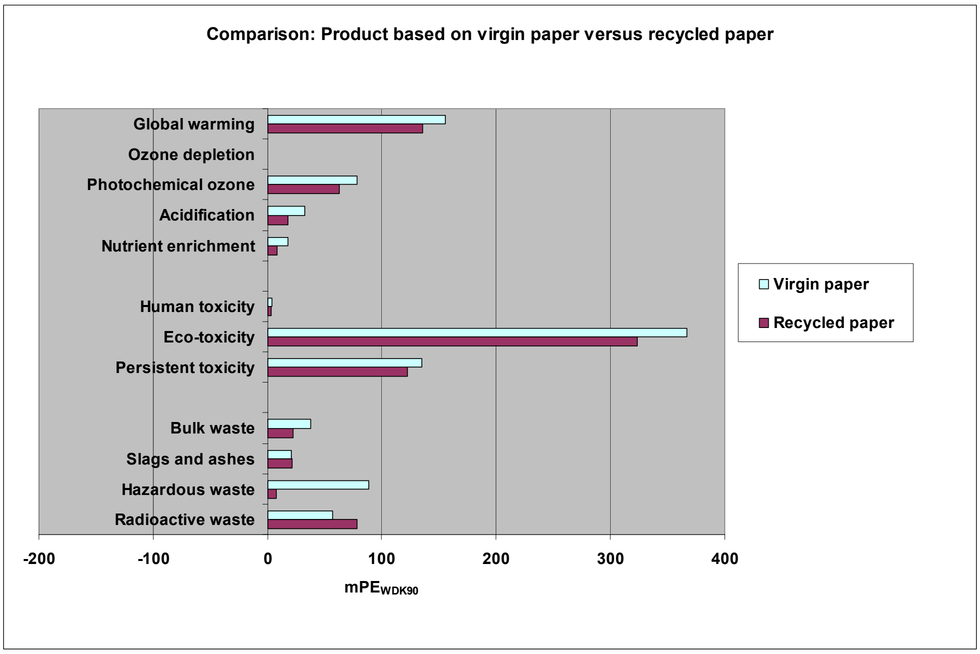


Fig. 22. Comparison of the normalized LCA profiles for the generic printed matter produced by use of virgin paper exclusively (reference scenario) or by use of recycled paper exclusively (scenario 2).

If the comparison illustrated in Figure 22 is expressed in aggregated impact the LCA profile for the product based on virgin paper accounts for 1780 mPET whereas the recycled paper based product accounts for 1490 mPET. In other words, these results indicate that changing the paper raw material from virgin to recycled leads to a reduction of 16% in the aggregated impact.

It should be noticed, as stressed earlier, that the world (and European) paper market today is not saturated but increasing and a demand for more paper (marginal approach) will lead to production of virgin paper. However should the demand for recycled paper decrease, leading to a collapse of the paper recycling system, the overall potential environmental impact (on a society level) will increase significantly. The comparison in Figure 22 is assuming a saturated paper market to illustrate a possible effect of a change in the paper raw material use at the model printing company if the lower potential impact from production of recycled paper (deinking pulp) is allocated to the functional unit.

3.6 Results of impact assessment: Variation in paper waste (scenario 3)

The effect of changing the paper waste amount at the model printing company from 32% to 3.3% of the total consumption is illustrated in Figure 23. In this case, the effect of reducing the paper waste (i.e. reducing the paper consumption) is a reduction in all impact categories. If expressed in aggregated impacts, the LCA profile for the product produced with 32% paper waste is 1900 mPET whereas the product produced with 3.3% paper waste accounts for

1700 mPET. So these results indicate that changing the paper waste fraction from 32% to 3.3% results in an 11% reduction in the total aggregated impact.

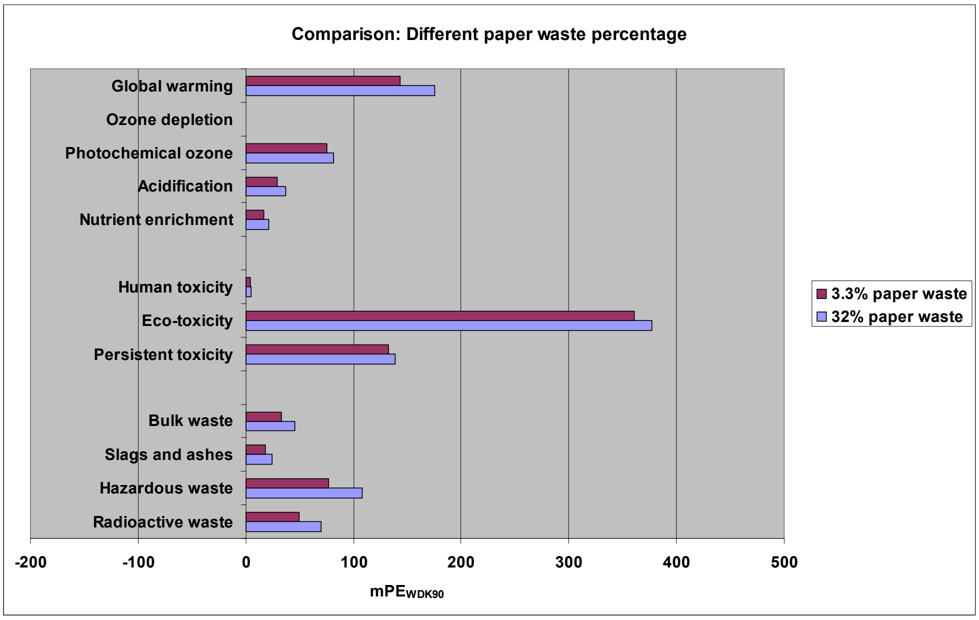


Fig. 23. Comparison of the normalized LCA profiles for the generic printed matter produced in a situation with 32% paper waste or in a situation with 3.3% paper waste.

3.7 Results of impact assessment: Variation in printing ink consumption (scenario 4)

Variation in printing ink consumption (observed: 1.8 kg/fu – 26.5 kg/fu) may to a high degree be due to variation in printing ink waste (observed: 2.4% – 45.9% of total consumption). In Figure 24, the effect on the normalized LCA profile of changing the ink consumption from 26.5 kg/fu to 1.8 kg/fu is illustrated.

As shown in Figure 24, the effect of changing the ink consumption is especially significant for the chemical related impact categories mainly due to reduced emissions at the model printing company and reduced emissions of toxic substances during the production of a reduced amount of pigments as a consequence of reduced ink consumption. A much smaller reduction in the energy related impact categories is also observed in Figure 24 connected to lower energy consumption to produce the smaller ink amount.

The consequence of reducing the ink consumption from 26.5 kg ink/fu to 1.8 kg ink/fu is a reduction from 2880 mPET to 1270 mPET when expressed in units of aggregated impact. This reduction is equal to 56%.

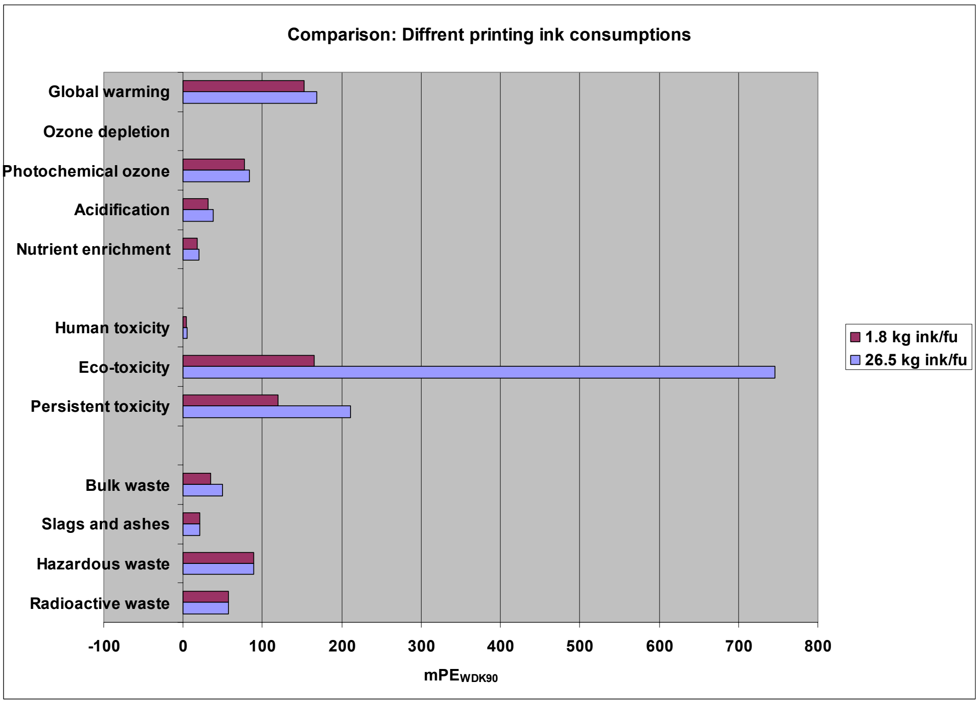


Fig. 24. Comparison of the normalized LCA profiles for the generic printed matter produced with 1.8 kg ink/fu or 26.5 kg ink/fu.

3.8 Results of impact assessment: Waste water treatment included (scenario 5)

The normalized LCA profile for a scenario where the substances emitted to the sewer by the model printing company are led to and treated in a wastewater treatment plant with biological step (WWTP) is shown in Figure 25. The fraction of each substance which is not degraded (mineralized), is emitted to either air, water or soil (i.e. via sludge used as fertilizer on arable soil) according to Table 14 in Section 2.4.5.

If we compare Figure 25 with Figure 2 (reference scenario), it is evident that the effect of the wastewater treatment is a reduction in the potential environmental impact in the chemical related impact categories – especially the impact category on ecotoxicity. In this category, printing is still dominant with 113 mPE though reduced by 54% as compared to the reference scenario. This reduction is primarily due to a 94% reduction in the amount of tetradecane emitted to water. If we disregard paper production, the second highest activity is now plate making accounting for 6.3 mPE after a 50% reduction mainly due to a 41% reduction in the water emission of Kathon. Furthermore, repro accounts for 4.3 mPE (63% reduction) primarily due to a 67% reduction in the water emission of hydroquinone, and finally cleaning is reduced to 3.1 mPE (94% reduction) mainly due to a 94% reduction in the emission of tetradecane to water.

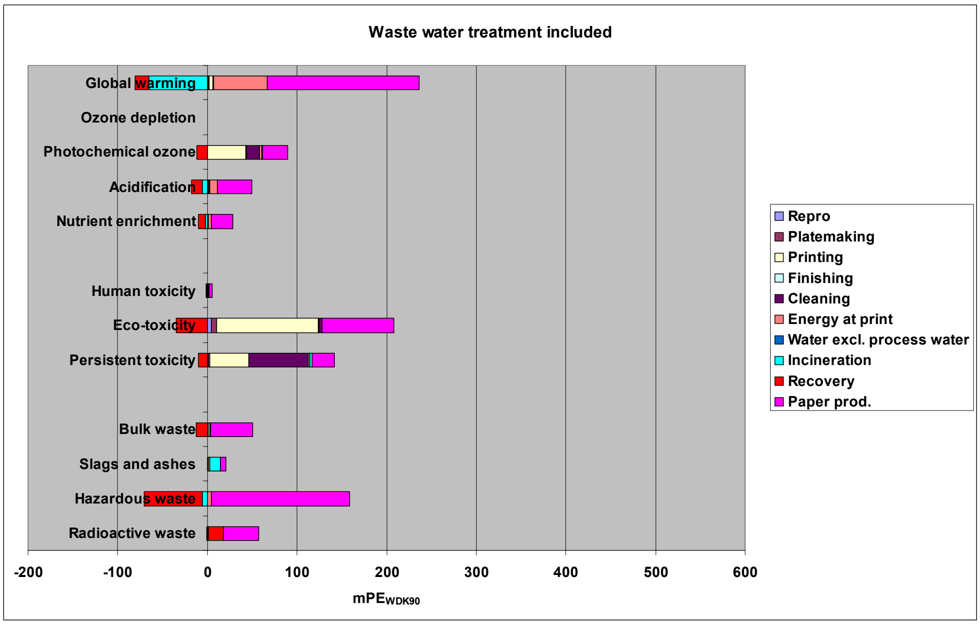


Figure 25. Normalized LCA profile for the scenario including WWTP (scenario 5).

In Figure 26 the LCA profile of scenario 5 including WWTP is compared to the reference scenario as totals within each impact category. The dominant effect on the impact category for ecotoxicity is evident. The consequence of including wastewater treatment is a reduction from 1780 mPET to 1320 mPET when expressed in units of aggregated impact. This reduction equals 26%.

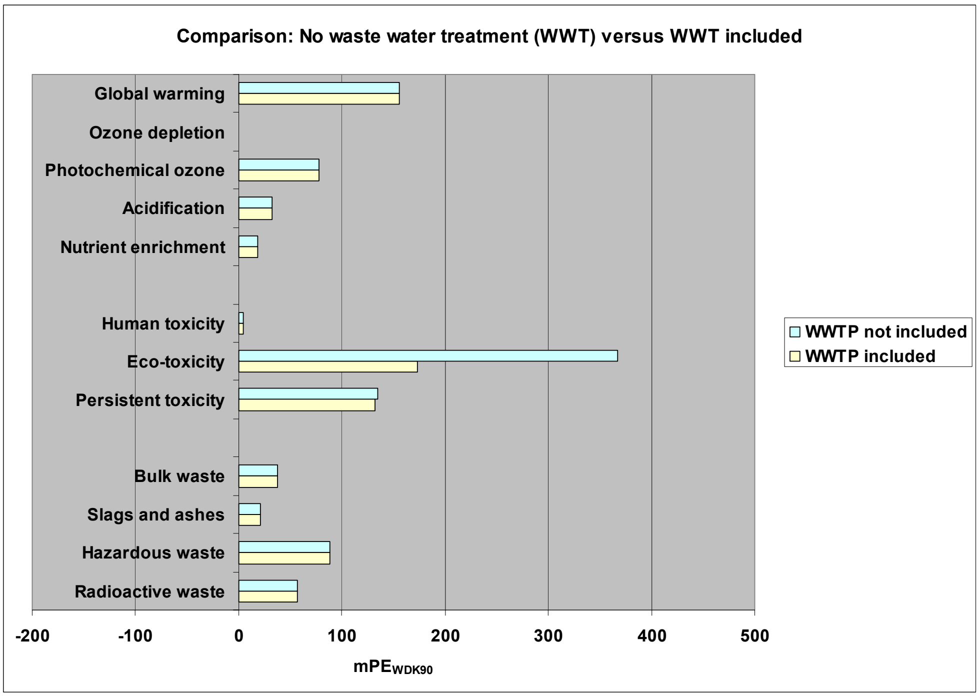


Fig. 26. Comparison of scenario 5 including WWTP with the reference scenario which is without WWTP.

If expressed in relative units (i.e. %) of the aggregated impact and divided into the different activities, the effect of including waste water treatment as compared to the reference scenario is a reduction from 41% to 32% for printing and an increase for paper from 31% to 41%. That is, the dominant position of printing is now taken over by paper as shown in Figure 27. Cleaning is reduced from 17% to 15% and energy consumption at the model printing company is increased from 6% to 9%.

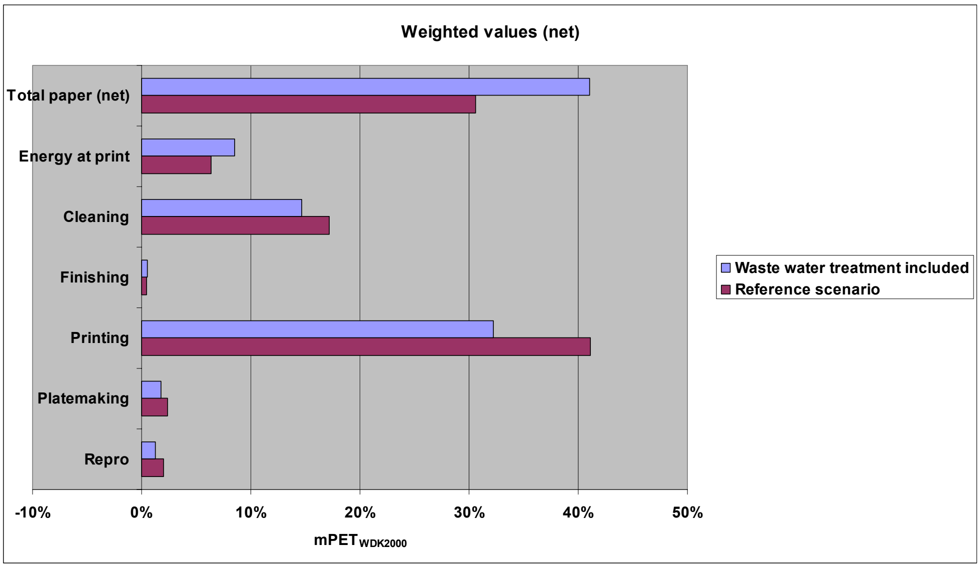


Figure 27. Comparison between the weighted LCA profile for the reference scenario and a scenario where wastewater from the model printing company is treated in a wastewater treatment plant (scenario 5). Expressed in percent share of total aggregated potential impact.

3.9 Results of impact assessment: Alternative biocide agent for rinse water (scenario 6)

To illustrate the effect of substitution of chemicals used at the model printing company on the normalized potential environmental impact scenarios with two different biocides for preservation of rinse water are compared in Figure 28. Figure 28 shows a comparison between scenario 5 described above where the biocide Kathon is used and scenario 6 where benzalkonium chloride is used as described in Section 2.4.6. For these two scenarios waste water treatment are included.

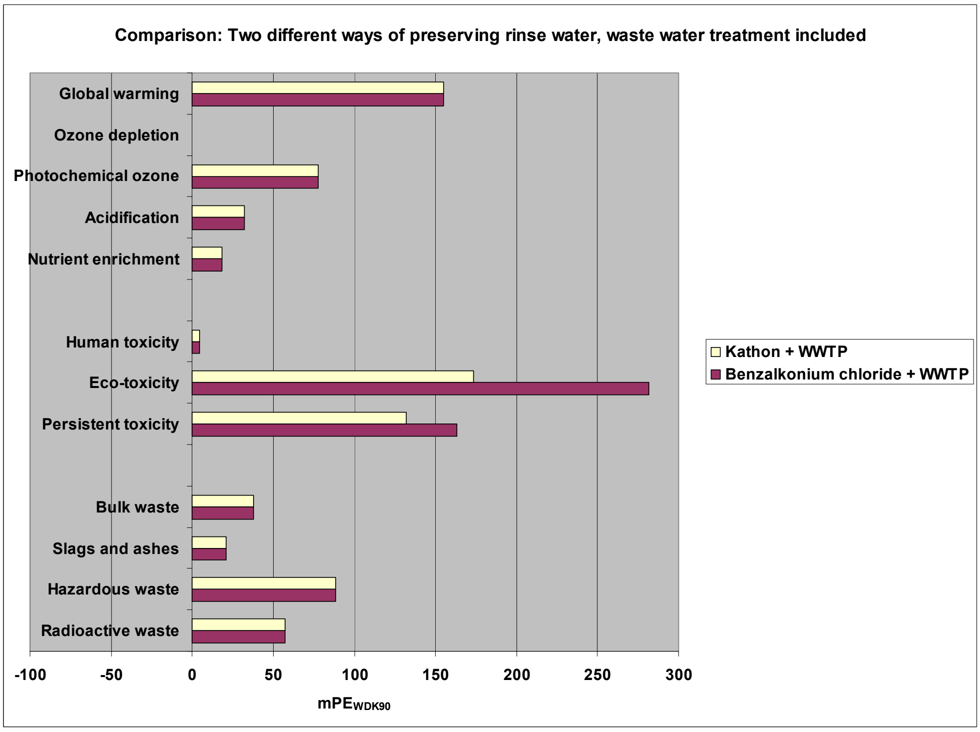


Fig. 28. Comparison of reference scenario using Kathon at recommended low dose with scenario 5 using benzalkonium chloride at recommended high dose, both for preservation of rinse water. Waste water treatment included.

The effect of substituting a recommended high dose of benzalkonium chloride with a low dose of Kathon (see Table 15 in Section 2.4.6) is evident from Figure 28. If the used rinse water is emitted to a WWTP the potential impact for the ecotoxicity impact category is reduced from 281 mPE to 173 mPE and for persistent toxicity the potential impact is reduced from 163 mPE to 132 mPE, see Figure 28. If the used rinse water is emitted directly to the water recipient the reduction is even more pronounced with a reduction from 1520 mPE to 367 mPE for ecotoxicity and 459 mPE to 135 mPE for persistent toxicity (not shown). This is due to the fact that only 10% of the benzalkonium chloride ends up in the water recipient after treatment in a WWTP whereas 59% of the treated Kathon ends up in the water recipient, see Table 14 in Section 2.4.5.

The effect of substituting benzalkonium chloride by Kathon in these scenarios including wastewater treatment is a reduction from 1680 mPET to 1320 mPET when expressed in units of aggregated impact. This reduction equals 21%. If wastewater treatment is not included the corresponding reduction is from 5740 mPET to 1780 mPET, which equals 69%.

3.10 Results of impact assessment: No waste water emitted (scenario 7)

In case no process waste water at all is emitted from the model sheet fed offset printing company, which is actually the case for some printing companies today, the normalized LCA profile becomes like the one shown in Figure 29.

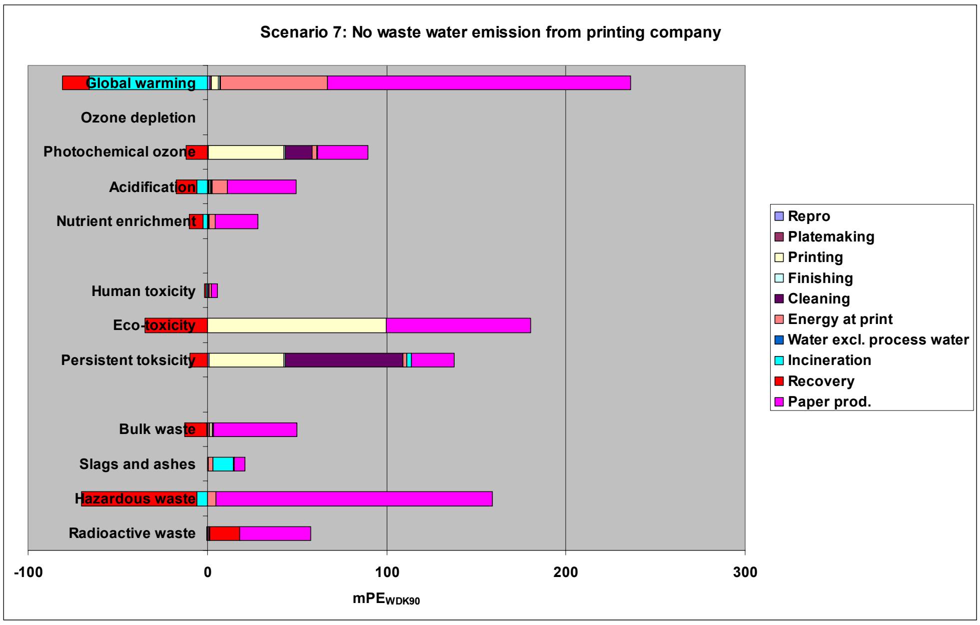


Figure 29. Normalized LCA profile for the scenario with no wastewater emission (scenario 7).

Because it is assumed that generated wastewater in this case is treated as chemical waste not contributing significantly to the impact category for hazardous waste the only significant changes are within the impact categories for ecotoxicity and persistent toxicity as shown in Figure 29. If we compare the profile in Figure 29 with the corresponding profile for the reference scenario (Figure 2, Section 3.3.1.1) and focus on the impact category for acute ecotoxicity it becomes evident that the highest reduction is within cleaning, undergoing a 99.96% reduction followed by repro and plate making both undergoing a reduction of 99.7%. Finishing (not visible in Figure 2) undergoes a 92% reduction and printing a 59% reduction. If we focus on persistent toxicity the reductions are much more moderate with the highest value of 93% for plate making followed by a 59% reduction for repro. Printing and finishing undergo a reduction of 4% each, whereas cleaning is only reduced by 0.3%. Energy consumption at the model printing company and activities outside the model printing company (e.g. paper production) are not changed.

In Figure 30 scenario 7 is compared with scenario 5 and the reference scenario. The effect of not emitting any waste water at the model printing company as compared to the reference scenario or scenario 5 (including WWTP) is a reduction from 367 mPE (reference scenario) or 173 mPE (scenario 5) to 146 mPE for acute ecotoxicity and a reduction from 135 mPE (reference scenario) or 132 mPE (scenario 5) to 128 mPE for persistent toxicity. These figures illustrate the fact that emission of wastewater from the model printing company contributes significantly to the impact category for acute ecotoxicity and to a much lesser degree to the impact category for persistent toxicity.

If expressed in units of aggregated impact, the effect of avoiding wastewater emission at the model printing company as compared to the reference scenario is a reduction from 1780 mPET to 1250 mPET and if compared to scenario 5 the reduction is from 1780 mPET to 1250 mPET. These reductions equal 30 % and 5% respectively.

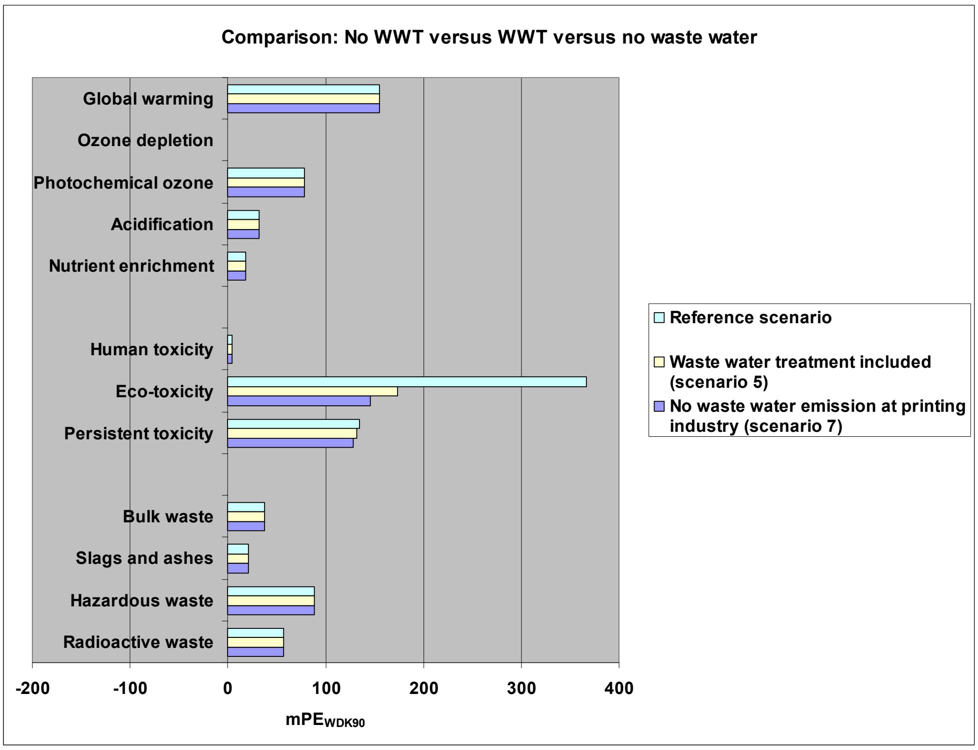


Figure 30. Comparison of a scenario with no wastewater emission at the model printing company (scenario 7) with a scenario with waste water emission and no waste water treatment (reference scenario) and with a scenario with waste water emission and waste water treatment (scenario 5).

4 Interpretation

4.1 Sensitivity analysis

The robustness of the reference scenario profiles on potential environmental impact to different alternations in normalisation references, weighting factors, disposal and more are evaluated below. Special focus is placed on the importance of paper as compared to the other elements (especially chemicals) of the life cycle because, as stated earlier, all existing LCA studies of printed matter point to paper as the overall dominating factor and focus on the energy related impact categories. Furthermore, the effect of varying the consumptions and emissions within the observed ranges for offset printing companies on the LCA profile (as already done for ink and paper, see Section 3.6. and 3.7) is further investigated including consumptions and emissions assessed to be of importance and relevant for ecolabelling.

4.1.1 Alternative normalisation references and weighting factors

Updated normalisation references and weighting factors for the EDIP method are soon going to be published and exist already today (April 2004) in the final draft report "LCA Guideline: Update on impact categories, normalisation and weighting in LCA. Selected EDIP97-data" (Stranddorf, Hoffmann & Schmidt 2004a). This report includes estimated normalisation references (NR) and weighting factors (WF) for the current 15 EU countries (EU-15) and the world plus updated values for Denmark. The normalisation factors for the EU-15 and especially the world are in many cases estimated on basis of emission data (inventories) for a few (or one) countr(y)ies extrapolated by using Gross Domestic Product (GDP) based on the assumption that there is a linear relationship between the economic activity of the (EU)country and its emission of substances contributing to the impact category in question (Stranddorf, Hoffmann & Schmidt 2004b). For example the normalisation references for ecotoxicity (aquatic acute and chronic) are for organic substances only based on data from the Netherlands (Tørsløv 2004). As pointed out by the authors themselves, the uncertainty is relatively high, for example above one order of magnitude for ecotoxicity. The weighting factors for EU-15, especially those for ecotoxicity and human toxicity (including persistent toxicity) are based on a limited data set omitting important groups of substances due to lack of common EU regulation and the lack of inclusion of single member state regulation (due to no readily available data according to the author (Busch 2004)). As pointed out by the author himself, the EU weighting factors for human toxicity and ecotoxicity are therefore most probably underestimated. The updated normalisation references (NR_{1994}) and updated weighting factors (WF_{2004}) are shown together with the normalisation references (NR_{1990}) and weighting factors (WF_{2000}) used in this study are shown in Table 19.

In order to see how the use of the new and updated normalisation references and weighting factors affects the LCA profiles for the reference scenario, a comparison between profiles based on existing and new factors is shown in Figure 31 and Figure 32 for a normalized profile and a weighted profile respectively. Only the existing and new factors for Denmark and EU-15 are included because the factors for the world are relatively identical to the factors for EU-15 or non-existing, see Table 19. The existing factors for the waste impact categories are used in all cases because no new ones exist. Furthermore the weighting factor for stratospheric ozone depletion covering the world (value 63) is used as part of the new weighting factors for Denmark (WF_{2004}) instead of infinite (∞).

Table 19. Normalisation references and weighting factors for the EDIP method.

Impact category	Unit	Normalisation references				Weighting factors			
		NR_{1990}*	NR_{1994}**			WF_{2000}*	WF_{2004}**		
		Denmark and world***	Denmark	EU-15	Global	Denmark and world***	Den-mark	EU-15	World
Global warming	kg CO_2-equiv./capita/year	8,700	8,700	8,700	8,700	1.3	1.11	1.05	1.12
Stratospheric ozone depletion	kg CFC-11-equiv./capita/year	0.202	0.103	0,103	0,103	23	∞	2.46	63/4.4#
Photochemical ozone formation	kg C_2H_4-equiv./capita/year	20	20	25	22	1.2	1.26	1.33	1.00
Acidification	kg SO_2-equiv./capita/year	124	101	74	59	1.3	1.34	1.27	-
Nutrient enrichment	kg NO_3-equiv./capita/year	298	260	119	95	1.2	1.31	1.22	-
Acute human toxicity (via air)	m^3 air/capita/year	$9.20 \cdot 10^9$	$2.09 \cdot 10^{9}$##	$3.06 \cdot 10^9$	$2.45 \cdot 10^9$	2.8	1.11	1.06	-
Chronic human toxicity via water	m^3 water/capita/year	59,000	179,000	52,200	41,800	2.9	1.02	1.3	-
Chronic human toxicity via soil	m^3 soil/capita/year	310	157	127	102	2.7	1.0	1.23	-
Acute ecotoxicity (aquatic)	m^3 water/capita/year	48,000	791,000	29,100	23,300	2.3	1.73	1.11	-
Chronic ecotoxicity in water	m^3 water/capita/year	470,000	74,000	352,000	282,000	2.6	1.67	1.18	-
Chronic ecotoxicity in soil	m^3 soil/capita/year	30,000	656,000	964,000	771,000	1.9	1.56	1	-
Persistent toxicity	-	-	-	-	-	2.5	1.31	1.18	-

* Existing values used in this study and included in EDIP97 (Wenzel, Hauschild & Alting (1997))
** Final draft updated and new factors according to Stranddorf, Hoffmann & Schmidt (2004a)
*** Global warming and stratospheric ozone depletion based on data for the world – the rest based on data for Denmark
# Industrialised countries/Developing countries
Most probably underestimated. Revised value is going to be included in the final report of the draft by Stranddorf, Hoffmann & Schmidt (2004a)

As is evident from Figure 31, the use of updated normalisation references for Denmark (NR-1994DK) or normalisation references covering the current 15 European Union member states (NR-1994EU-15) instead of the existing ones (NR-1990, EDIP97) does not change the overall picture of a profile dominated by contribution from the chemical related impact categories (categories covering (eco)toxicity).

The effect of using alternative normalisation references is, as shown in Figure 31, relatively moderate for the energy related impact categories. Global warming is constant and photochemical ozone formation is only reduced by 20 % if NR-1994EU-15 is used instead of the existing one (NR-1990). For acidification the normalized potential impact is increased by 23% and 67% respectively if the existing normalisation reference is substituted by the one for Denmark 1994 or EU-15. The effect on nutrient enrichment is also an increment for DK1994 and EU-15 if compared to NR-1990 with values of 14% and 150% respectively.

For the chemical related impact categories the effect of using alternative normalisation references is much more striking. The effect of using normalisation references from DK1994 instead of the existing ones is an increment of 3100% for acute human toxicity (probably too high, see Table 19), a reduction of 94% for acute ecotoxicity and an increment of 260% for persistent toxicity. If the EU-15 normalisation references are used instead of the existing ones the value for acute human toxicity is increased by 200%, the value for acute ecotoxicity is increased by 65% and for persistent toxicity the increment only accounts for about 6%.

If we look at the two impact category groups, i.e. the energy related one and the chemical related one, and sum up the normalized contributions within each group disregarding weighting (i.e. WF = 1 for all impact categories) and the waste impact categories we arrive at the figures shown in Table 20.

Table 20. Comparison of the result of using different normalisation references for calculating the total normalised potential impact within energy related and chemical related impact categories. Percent change as compared to NR-1990 shown in brackets.

Normalisation references used	Total normalised potential impact*	
	Energy related impact categories **	Chemical related impact categories ***
NR-1990	284	508
1994DK	294 (+4%)	642 (+26%)
1994EU-15	317 (+12%)	764 (+50%)

* Not weighted, i.e. WF = 1 for all impact categories
** Global warming, photochemical ozone formation, acidification and nutrient enrichment
*** Acute human toxicity, acute ecotoxicity and persistent toxicity

As is evident from Table 20, using alternative normalisation references increases the impact potential for the chemical related impact categories more than the energy related ones hereby further strengthen the dominant position of the chemical related impact categories in the normalised profile for a generic printed matter.

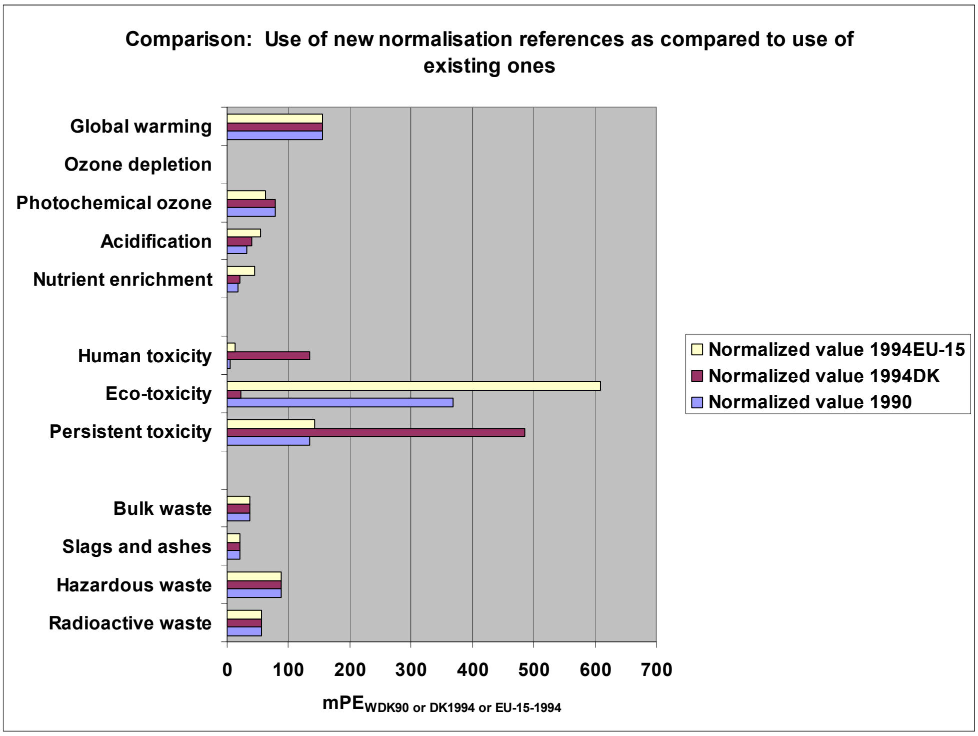


Figure 31. Comparison of the normalized profile for the reference scenario based on existing normalisation references (1990 from EDIP97), new final drafted values for Denmark (1994DK) and final drafted values for EU (1994EU-15).

If we look at the weighted profiles shown in Figure 32, the effect of using alternative weighting factors is a reduction in the potential environmental impact for most of the impact categories. The highest reduction is observed in the impact category for acute ecotoxicity, i.e. 25% for 1994DK and 52% for EU-15 if compared with the weighted value based on existing weighting factors. The reduction for persistent toxicity is also relatively high, accounting for 48 % and 52% for 1994DK and EU-15 respectively if compared with the weighted value based on existing weighting factors.

If we do the same grouping for the weighted values as for the normalised ones we produce the figures shown in Table 21.

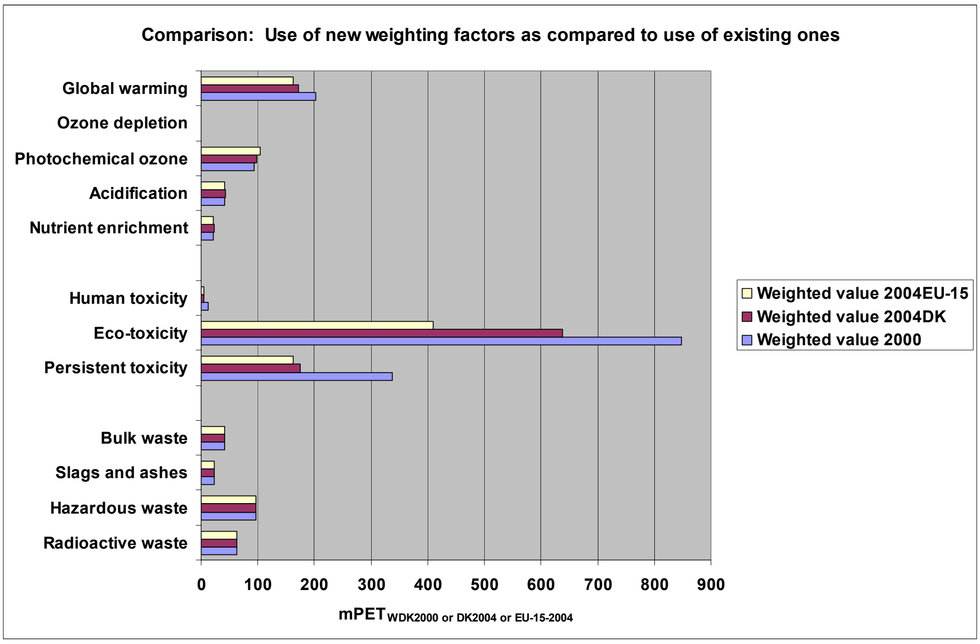


Figure 32. Comparison of the weighted profile for the reference scenario based on existing weighting factors (2000, from EDIP97), new final drafted values for Denmark (2004DK) and final drafted values for EU (2004EU-15).

The figures in Table 21 show a reduction of more than 50% in the total for the chemical related impact categories if the EU-15 weighting factors are used instead of the existing ones. The corresponding reduction in the energy related impact categories is only 8%. However most of the reduction in the chemical related impact categories may be due to the fact that the EU-15 weighting factors for the chemical related impact categories most probably are underestimated (Busch 2004) as mentioned above.

Table 21. Comparison of the result of using different weighting factors to calculate the total weighted potential impact within energy related and chemical related impact categories. Percent change as compared to WF-1990 shown in brackets.

Weighting factor used	Total weighted potential impact	
	Energy related impact categories *	Chemical related impact categories **
WF-1990	359	1200
1994DK	337 (-6%)	818 (-32%)
1994EU-15	330 (-8%)	576 (-52%)

* Global warming, photochemical ozone formation, acidification and nutrient enrichment
** Acute human toxicity, acute ecotoxicity and persistent toxicity

In Figure 33 the weighted profile based on the EU-15 weighting factors and separated into the different activities is shown. If we compare this figure with Figure 6 in Section 3.3.2.1 (weighted profile based on existing weighting factors) the reductions mentioned above in the impact categories, especially for persistent toxicity, are evident. However as may be interpreted from the comparison of the two figures these reductions only change the distribution of the relative importance among the different activities to a minor degree. This fact is illustrated in Figure 34 where the relative importance of the different activities in the two cases are compared.

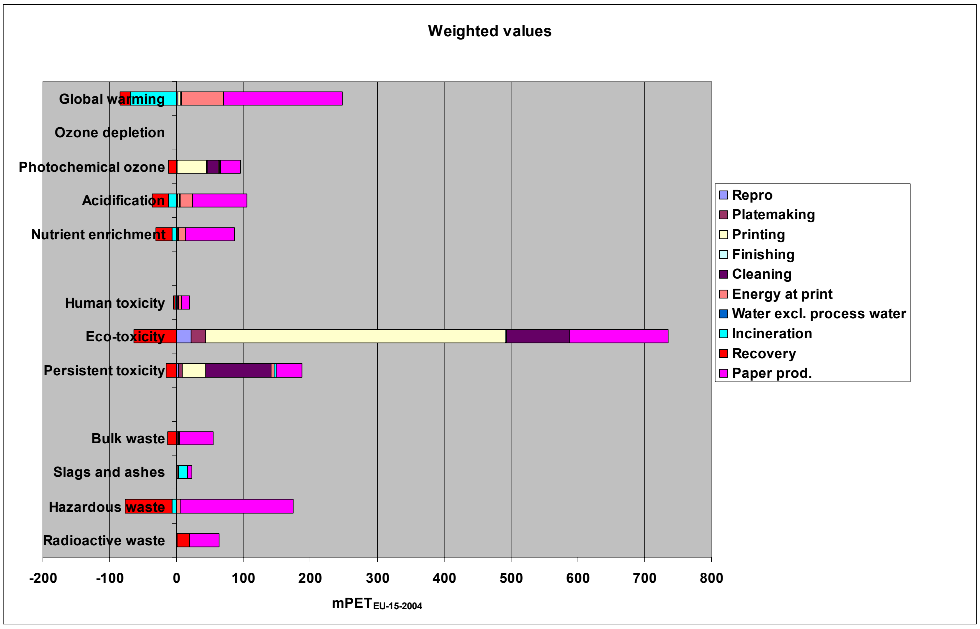


Figure 33. Weighted profile for a reference scenario where existing normalisation references and weighting factors are substituted by new drafted ones for the 15 current European Union member states (EU-15).

As shown in Figure 34 the effect of using the NR's and WF's for the current 15 EU member instead of the ones used in the reference scenario (mainly Danish) is an absolute increment of the importance of the paper production from 31% to 36% whereas printing is reduced from 41% to 37% making paper and printing about equally important. Cleaning is reduced in importance from 17% to 15% whereas energy consumption at the printing house is increased from 6% to 8% in importance. The other activities only undergo very small changes. This comparison shows that changing the NR's and WF's in the reference scenario to EU-15 values only has a minor influence on the distribution of importance among activities. It does not change the overall picture. Furthermore, if we take into account that moderate or small increases in the EU-15 weighting factors for acute ecotoxicity (e.g. 1.11 changed to 1.7) and persistent toxicity (e.g. 1.2 changed to 1.3) – which are both most probably underestimated – will lead to an increase in importance for printing from 41% to 43% and keep paper production and energy consumption at the printing house unchanged at 31% and 6% respectively, the difference between the two cases may be considered as negligible. The weighted reference scenario used in this study is therefore considered as robust and valid on a European scale.

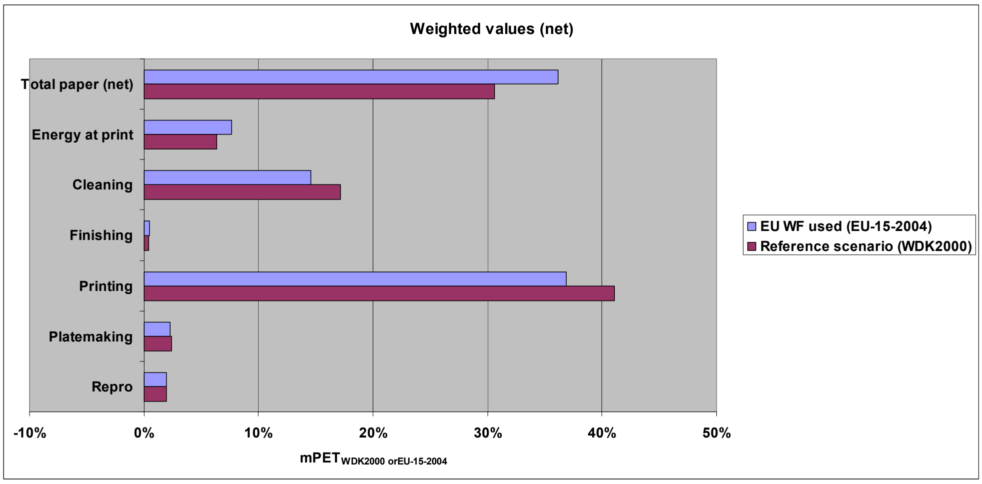


Figure 34. Comparison of relative importance distribution for the reference scenario (using existing NR and WF, WDK2000) and for a reference scenario using new drafted NR's and WF's (EU-15).

4.1.2 Allocation for paper production

As described in Section 1.1.2.7 two approaches for allocation on paper are used in this study, i.e. paper gross (avoided potential impacts from incineration and recycling are not allocated to the paper) and paper net (avoided potential impacts from incineration and recycling are fully allocated to the paper). If we instead use the "cut off" allocation principle INFRAS (1998), i.e. all potential environmental impacts are allocated to the virgin paper production (primary production) and the paper (including the printed matter) for recycling is considered as raw material for a new production process not carrying any burdens from the primary process, only the negative contribution from incineration is allocated to the paper used in our functional unit. This would result in a contribution of 43% (48% - 5%) to the aggregated impact; see Figure 8 in Section 3.3.2.1. On the other hand if we use the quasi-co-product allocation principle as described in INFRAS (1998) we will (if the same energy scenario is used at all cycles) see a significant reduction in the contribution from paper per functional unit. This is because in our case we would assume three cycles for the paper (i.e. chemical pulp reused twice) leading to a production of 3 co-products equally sharing the extra potential environmental impact from production of the primary product (based on virgin fibres). However, this allocation principle demands that the same functional unit can be used for all co-products and this is not true in our case because sheet fed offset to a very high degree uses virgin paper, which is reflected in an utilisation rate of only 8.6% for printing and writing paper (CEPI 2003). The recycled high-grade paper from sheet fed offset is therefore used after repulping for other product types such as packaging to a very high degree. We have therefore chosen in this study to use the paper (net) as the principle where recycling is taken into account in the functional unit, i.e. avoided fossil fuel consumption (including emission etc.) due to incineration of paper and the avoided energy consumption (including emission etc.) due to production of sulphate pulp (actually de-ink pulp) on the basis of recycled paper are fully allocated to the paper used for production of one functional unit.

4.1.3 Most important factors for the LCA profile

Some of the emissions and assumptions about the scoping of the reference scenario etc. included in this study are very crucial for the resulting LCA profile. The most important of these factors are dealt with below.

4.1.3.1 Paper

The production of paper is one of the most important activities in the life cycle of sheet fed offset printed matter. In the reference scenario paper production accounts for around 540 mPET/fu corresponding to 31% of the aggregated impact when recovery of energy and avoided emissions from recycling and incineration are allocated to paper production.

The outcome of the LCA profile for printed matter is very dependent on the energy scenario chosen for the paper and pulp production as described in details by INFRAS (1998) using site specific scenarios. However, in our generic study we avoid this problem to a high degree by using a marginal approach for electricity production.

The importance of paper production (from cradle to gate) is documented in several earlier LCA studies on offset printed matter (Dalheilm & Axelsson 1995, Axelsson et al 1997, INFRAS 1998, Johansson 2002 and Drivsholm et al. 1997). However the result of these studies shows an importance for paper that is more than twice as big (typically 70% – 80%) as the one found in this study (i.e. the reference scenario). In the study by INFRAS (1998) the importance of paper accounts for only about 64% in the main scenario (site specific), which may be due to the fact that the potential impact from nuclear power and hydro power (dominant in the energy scenario) are not included. The main reason that the importance of paper in this study is lower than half of the importance in the existing studies mentioned above is (besides differences in product types and methodology including allocation) most probably that emissions of chemicals contributing to the chemical related impact categories are included to a higher degree than in the existing studies. The effect of excluding the chemical related impact categories from the reference scenario is shown in Figure 35. The result is that the importance of paper is increased to 67%, which is at the level of the previous studies.

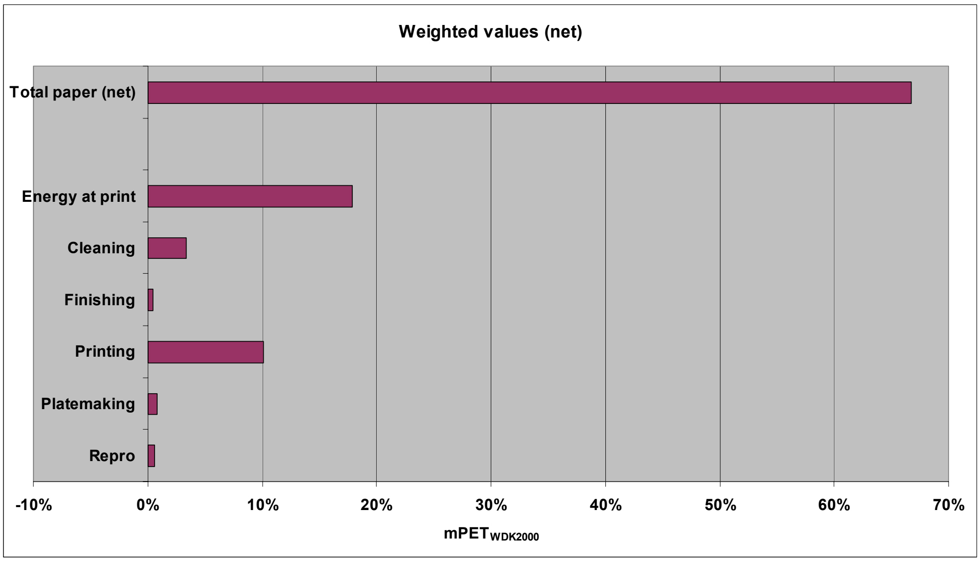


Figure 35. Weighted LCA profile for the reference scenario where chemical related impact categories are excluded. Expressed in percent share of aggregated impact.

Due to the lack of readily available data on the use of pesticides in forestry (as described qualitatively in Drivsholm et al. 1996) it has not been possible to include this potential contributor to the chemical related impact categories.

Known emissions during paper production in the reference scenario that it has not been possible to take into account in this study include AOX (107 g Cl/fu), biocides, chelating agents a.m.

AOX is a sum-parameter (expressed in mass of chlorine) covering halogenated (e.g. chlorinated) organic substances created during the bleaching of paper pulp if done by use of chlorine or chlorine dioxide containing agents. Bleaching with chlorine dioxide is called elementary chlorine free (ECF) bleaching whereas bleaching without any use of chlorine containing molecules (e.g. by use of peroxides) is termed total chlorine free (TCF) bleaching. In this LCA ECF bleached paper is included. In the study by INFRAS (1998) an analysis of the AOX issue is done. The conclusion is that the AOX emission from modern ECF bleaching processes (as included in that study and dominant today) does not contribute at all significantly to the potential impact of the LCA on printed matter. This conclusion is based on the estimation of an AOX-factor (characterisation factor) for the CML-method and calculating the contribution from AOX to the impact category "ecotoxicity water" on that basis. The AOX factor is estimated on basis of an assumption that the AOX can be represented by 85% monochloranilin, 7.5% dichlorobenzene and 7.5% of a fictitious substance with the average potential impact of trichlorobenzene and tetrachlorobenzene. The result is an AOX-factor of 0.14 points/g AOX which is pretty close to the factor for dichlorobenzene, i.e. 0.16 points/g dichlorobenzene. This estimated AOX-factor is of course only an approximation and based on the available characterisation factors for mono-, di-, tri- and tetra- chlorinated aromatics in the CML-method at that time (Heijungs et al. 1992) for which the characterisation factors were based on maximum tolerable concentrations and expressed in critical volume ("m^3 polluted water") with no fate part included. The toxicity and fate of different mono-, di-, tri- and tetra- chlorinated aromatic compounds vary considerably. However it seems quite strange that the CML-factor (on ecotoxicity water) for monochloroanilin is 0.01 points/g whereas the factor for dichlorobenzene is 0.16 points/g (i.e. a factor 16 more toxic) (Heijungs et al. 1992) even though the toxicity of monochloroanilin is about 10 times higher (based on No Observed Effect Concentration, NOEC's) than that of dichlorobenzene according to the compilation of several toxicity data on these two substances by RIVM (1999) and Reuther, Crommentuijn & van de Plassche (1998). The reason might be that the CML-factors are estimated on the basis of a poor database. Anyway, if we accept the estimations by INFRAS (1998) and use dichlorobenzene to represent the AOX emission in our case (AOX =107g Cl/fu) we arrive at an emission of 222 g dichlorobenzene/fu and by multiplying by the EDIP characterisation factors for dichlorobenzene (Hauschild and Wenzel 1998), and further perform normalisation and weighting, the resulting contribution from the AOX emission is 116 mPET (paper gross) or 57 mPET (paper net). These figures correspond to about a 30% rise in the potential impact from the chemical related impact categories of paper. In the aggregated impact for the reference scenario (i.e. 1780 mPET/fu) the rise of 57 PET will result in an importance of AOX emission from paper production of about 3%. This estimation indicates that AOX emission from paper production may be important in the life cycle of sheet fed offset printed matter. According to the INFRAS study (INFRAS 1998) the "very small but still measurable sub lethal toxic effects" observed in fish populations exposed to waste water from modern ECF (or TCF) paper mills are not due to bleaching but maybe due to emission of "natural insecticides" and preservatives present in the wood. That sub lethal effects still occur in fish communities exposed to waste water from ECF paper mills has recently been documented by Sand & Newman (2003).

Biocides like Kathon are used for preservation in the paper production but the amount emitted is not known.

Even though it would have been nice if emission of AOX and biocides from paper production could have been included in the calculation of the chemical related impact categories, it is assessed that the heavy metal emission from the paper production (which is included) probably covers the major part of the chemical related potential environmental impact from the paper production. Furthermore it should be noted that also for other activities in the life cycle it has not been possible to include all potential contributing emissions. For example for printing, as earlier mentioned, it has not been possible to include water emission of siccatives. Even though it is considered that the most important emissions are covered - given the presently available knowledge - this missing contribution within printing may counteract the missing contribution from paper production, leading to no significant changes in distribution of relative importance between paper production and printing.

As described in Section 3.6 for scenario 3, the effect of changing the amount of paper waste per functional unit (actually the paper consumption) is significant for the outcome of the LCA profile. As depicted in Table 12 (Section 2.2.) the observed range in paper consumption is 1030 kg/fu – 1470 kg/fu. If we use these figures for recalculation of the reference scenario (all other factors constant) we end up with a net importance for paper of 28% for the lowest consumption and 35% for the highest consumption as compared to 31% in the reference scenario. These results illustrate the relative high importance of paper consumption in the life cycle of sheet fed offset printed matter. However due to the fact that the average consumption value used in the reference scenario is based on the actual consumption at more than 70 offset printing companies' makes this value robust as input to this generic LCA.

Another issue that seems more crucial for the outcome of the estimated importance of paper is the choice of scenario for paper disposal/recycling. In the reference scenario 53% of the paper is recycled (actually recovered) and the rest is incinerated with energy utilisation. This scenario covers paper in general and is valid for Denmark, but in other European countries it may be different. According to the newest recycling statistics from the Confederation of European Paper Industries (CEPI) (CEPI 2003) covering 2002 the average recycling rate in the EU countries is about 53%, which is identical to the rate used in the reference scenario. However differences exist between the different EU member countries, which are reflected in the paper collection rate (average 56%) with a range of about 45% (e.g. Portugal and Italy) to about 70% (e.g. Finland and Germany) according to CEPI (2003).

On a European scale, paper not recovered is mainly disposed of as waste for either land filling or incineration. If we assume that at least the main part of this paper is disposed of as municipal waste we can use the data from EUROSTAT (2002) to estimate the average European partition between incineration and land filling for the paper waste. According to EUROSTAT (2002) 271 kg municipal waste per EU capita was land filled in 2002 whereas 102 kg municipal waste per EU capita was incinerated the same year. These figures gives an average estimate of about 70% paper wasteland filled and about 30% paper waste incinerated in EU. By using these figures we end up with 53% paper for recycling, 33% for land filling and 14% for incineration. In the INFRAS study (INFRAS 1998) based on a disposal scenario for Germany a split of 60% for recycling, 26% for land filling and 14% for incineration is used. Due to anaerobic conditions in the land fillings the paper deposited will during decomposition evolve methane, which is emitted to air. Methane emissions contribute to global warning and if we assume that the methane generation accounts for 0.3 kg methane/kg paper (Dailheilm & Axelsson 1995), which is a theoretical maximum, we end up with an extra contribution to global warming of 2960 kg CO_2-equiv./fu in this alternative reference scenario. The LCA profile based on aggregated impacts for this alternative reference scenario is shown in Figure 36.

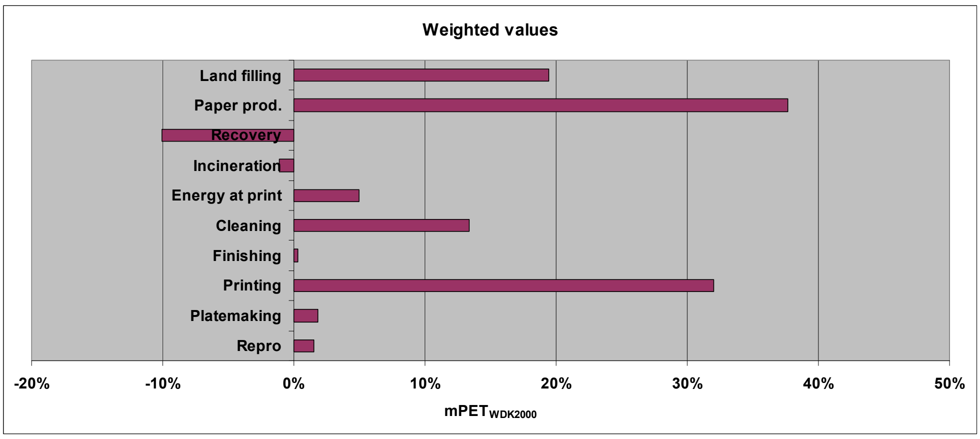


Figure 36. Weighted LCA profile for the alternative reference scenario where land filling of paper waste is included. Expressed in percent share of aggregated impact.

As is evident from Figure 36, land filling contributes significantly (19%) to the LCA profile leading to a reduction in the importance of all the other activities.

If we allocate the contribution from land filling to paper we reach the profile shown in Figure 37 together with the profile for the reference scenario.

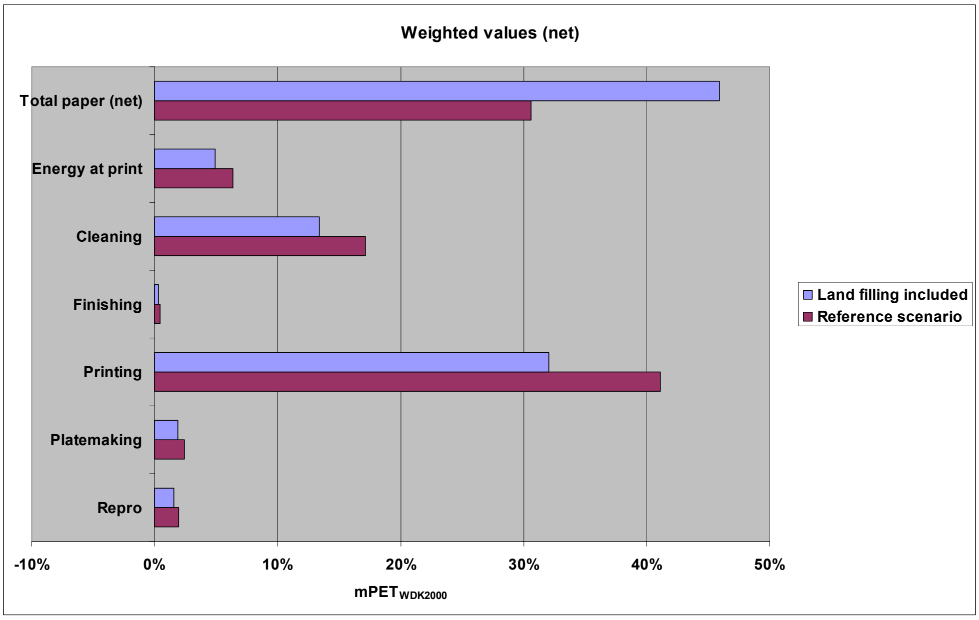


Figure 37. Comparison between the weighted LCA profile for the alternative reference scenario where land filling of paper waste is included and the reference scenario. Contributions from recycling, incineration and land filling of paper allocated to "Total paper (net)". Expressed in percent share of aggregated impact.

As shown in Figure 37, the effect of including land filling is an increase in the relative importance of paper from 31% to 46% and a reduction in the importance of printing from 41% to 32%. Also the importance of the other activities is reduced, e.g. cleaning is reduced from 17% to 13% and energy consumption is reduced from 6% to 5%.

The recycling rates used here are based on a European average for paper in general. However about 19% of the paper on the market is not recyclable, comprising hygiene paper, cigarette paper, papers used for construction materials a.m. (CEPI 2003) leading to a recycling rate for recyclable paper (such as sheet fed offset printed matter) og 65%. If we use this rate we end up with 65% paper for recycling, 25% for land filling and 10% for incineration leading to an alternative reference scenario with the profile shown in Figure 38.

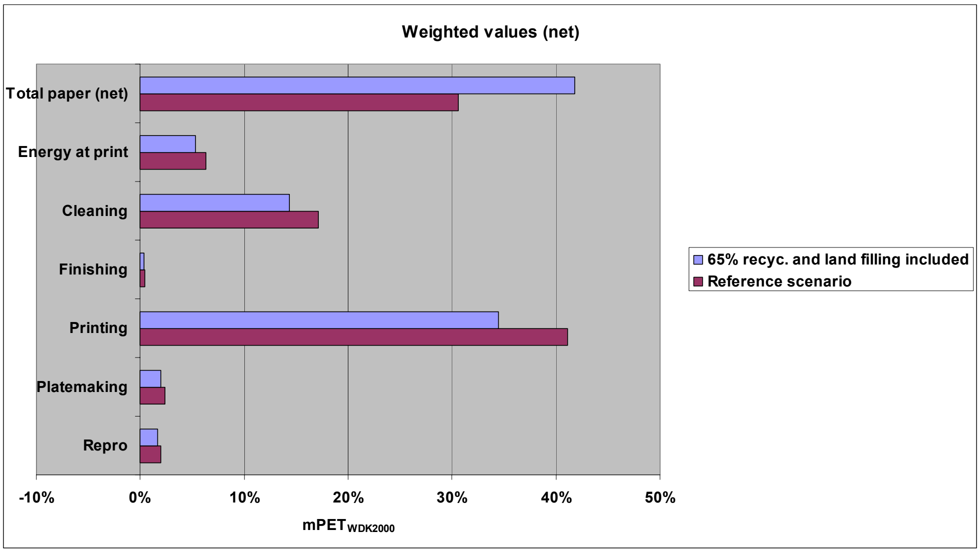


Figure 38. Comparison between the weighted LCA profile for the alternative reference scenario where 65% recycling of paper and land filling of paper waste is included, and the reference scenario. Contributions from recycling, incineration and land filling of paper allocated to "Total paper (net)". Expressed in percent share of aggregated impact.

As is evident from Figure 38, the importance of paper is now increased from 31% to 42% and the importance of printing only reduced from 41% to 34%. Furthermore cleaning is only reduced from 17% to 14% when compared to the reference scenario.

The alternative reference scenarios shown in Figure 37 and Figure 38 are both based on the assumption that methane emission from land filling can be included as a worst case. However the following points all point in the direction of a reduced importance of methane emissions:

- The recycling rate for sheet fed offset printed matter (including paper waste from the printing company, average 16% of consumption) is probably substantially higher than 65% due to the fact that high-grade paper quality is used.
- The methane generation rate of 0.3 kg methane/kg paper is worst case assuming that all carbon (part of cellulose) in the paper is converted to methane and nothing to CO_2 (e.g. due to oxidation in the upper layer of the land fill)
- Utilisation of methane from landfills for energy productions actually occur in Europe but the extent is unknown.

Unfortunately no quantitative data has been readily available for these three points. However if it is assumed that only 65% of the paper used for sheet fed offset is recycled but that 50% of the generated methane is utilised for energy production (avoided burning of fossil fuel not allocated to the functional unit) or otherwise oxidised to CO_2 the LCA profile for this alternative reference scenario will be identical to the reference scenario (i.e. importance of printing 41%, importance of paper 31% etc.). Further, if the worst case for methane emission is assumed but 85% recycling of paper, the importance of paper becomes 39% and that of paper 34%. A combination of 30% of generated methane utilised and 80% paper recycled also leads to an importance of printing of 39% and paper 34%.

These estimations are based on assumption that are most probably closer to the truth than the estimations shown in Figure 37 and Figure 38 based on assumptions of a relatively low recycling rate for high grade graphic paper and worst case methane emission from land filled paper waste. It is therefore assessed that the inclusion of land filling of paper waste does probably not change the LCA profile for sheet fed offset printed matter substantially and the reference scenario is therefore assessed to be sufficient robust to represent the average European situation on paper disposal.

4.1.3.2 Printing

That the processes occuring at the printing company (upstream processes included except for paper) have a significant importance for the LCA profile of offset printed matter is documented in some earlier studies (Dalheilm & Axelsson 1995, Axelsson et al 1997, INFRAS 1998, Johansson 2002 and Drivsholm et al. 1997). However all these studies point to a much lower importance of the printing company processes than this study. For example in the INFRAS study (INFRAS 1998), looking at a newspaper, the importance of processes occuring at the printing company is estimated as 31% (35% if distribution is included) by use of the Eco-Indicator-95 method. In our study the corresponding importance is as high as 69%. Besides differences in the product types and methodology used including allocation principle for paper the main reason for this difference is assessed to be that the chemical related impact categories in our study are included to a higher degree than in the earlier studies, e.g. emission of specific non-energy related substances in upstream processes are not taken into account in the INFRAS study, see Introduction and Section 4.1.3.1 for further details.

Printing is in this study the most important factor contributing with 730 mPET/fu corresponding to 41% of the aggregated impact. However in our case it includes at least two main sub activities, i.e. printing ink production and the printing process at the model printing company.

Production of printing ink contributes in the reference scenario with 295mPET corresponding to 17%. As described in Section 3.2.1 this contribution is mainly due to relatively high characterisation factors based on emissions scenarios taken from the EC Technical Guidance Document (TGD) on risk assessment (EC 2002). This kind of scenario is used for first tier risk assessment/screening and may therefore be conservative. However, Andersen & Nikolajsen (2003) have consistently used the lowest among the proposed values for emitted fraction in every case (produced amount > 2000 ton, assuming WWTP at the production facilities). A brief critical review of the calculations by Andersen & Nikolajsen (2003) reveals errors in the estimated chronic characterisation factors for the two most contributing synthesis chemicals, i.e. 3,3-dichlorobenzidine and cuprous chloride. If these errors are taken into account, the chronic aquatic characterisation factor ($EF_{(etwc)}$) in Table 16 (Section 3.2.1) for Pigment Yellow 14 upstream becomes 42.5 m^3/g instead of 9.26 m^3/g (a factor 5 higher) and for Pigment Blue 15 upstream the chronic aquatic characterisation factor ($EF_{(etwc)}$) in Table 16 becomes 48.3 m^3/g instead of 10.4 m^3/g (also about factor 5 higher) and the chronic terrestrial characterisation factor ($EF_{(etsc)}$) in Table 16 becomes 4.89 m^3/g instead of 1.29 m^3/g (about a factor 4 higher). If these corrections are taken into account the contribution to the aggregated impact from the ink production is increased from 295 mPET to 371 mPET leading to an increase in the importance from 17% to 20% for the ink production and a simultaneous reduction in the importance of, for example, total paper from 31% to 29%. The result of this correction points in the direction of a slightly higher importance of the ink production in the reference scenario. Furthermore it is known that pigments are part of the positive offset plate emulsion used at the plate making activity, but it is assessed that this consumption (due to low quantity) does not contribute significantly to the aggregated impact from pigment production. Actually measured emissions from the production of pigments would have been preferred, but this kind of data is unfortunately not readily available today.

The very high importance of the ink consumption at the model printing company is shown in Section 3.7 (scenario 4). A further analysis of these results based on the observed range of 1.8 kg ink/fu – 26.5 kg ink/fu reveals a range in the importance of 7% - 34% for ink production and 7% - 37% for ink residue emission at the model printing company. In total this gives an importance of printing (incl. ink production) of 23% in the lower consumption case and 74% in the upper consumption case. The corresponding importance for paper (net) is 40% and 14% respectively. However these calculations are based on the assumption that the emission of ink residues at the model printing company is directly proportional to the consumption. This is probably not true. If we assume that the ink emission is independent of the consumption, the result reveals a 34% importance of printing (incl. ink production) in the lower consumption case and 63% importance in the upper consumption case. For paper (net) the corresponding figures are 35% and 19% respectively.

Emission of ink residues at the model printing company contributes 316 mPET corresponding to 18% of the total in the reference scenario. The overall dominating contributor is emission of tetradecane which is as described in Section 2.1.10, included to represent the solvent part (mineral oil) of the printing ink. In this generic LCA the emission of ink residues is assumed to be via used fountain solution and to a lesser extent cleaning agents/water emitted as waste water to water, see table 13 in Section 2.3. The amount emitted is set to 1% of the ink consumption. No measured range in ink residue emission is known but if we assume a variation of a factor 10 (range: 0,3% - 3%) and use these figures to recalculate the reference scenario we get an importance of 6% (95 mPET) for the lower value and 39 % (950 mPET) for the upper value. These recalculations will simultaneously lead to an importance of the printing activity (total) of 33% (lower value) and 57% (upper value) and for total paper (net) of 35% (lower value) and 23% (upper value). These results illustrate a high importance of ink residue emission for the generic LCA of sheet fed offset printed matter. The amount actually emitted at a sheet fed offset printing company will depend on factors such as whether or not the used fountain solution and waste water from cleaning (e.g. dampening form rollers with cloth) are emitted to water, and if emitted, the concentration of ink residues in, for example, the used fountain solution which depends on the fountain solution system at the printing machine. However it is assessed that an emission of 1% of consumption represents emission of ink residues for a generic sheet fed offset LCA fairly accurately.

Emission of IPA at the model printing company (especially air emission) also contributes significantly, i.e. 100 mPET, corresponding to 6%. The range in the consumption is 0.0785 kg/fu - 10.4 kg/fu as depicted in table 12 in Section 2.2. If we use these two values to recalculate the reference scenario we obtain an importance of 0.1% in the lower case and 7% in the upper case. These results indicate that the importance of IPA is only moderately raised if used in the highest observed quantity and that it may be reduced to insignificance if the lowest observed consumption is used. Here it is assumed that the emitted amount of IPA is directly proportional to the consumption, which is assessed to be realistic in this case because IPA is an auxiliary substance not following the product.

The last factor within printing that contributes more than 1% to the aggregated impact of the reference scenario is the fountain solution. This contribution (1.1%) is primarily connected to the biocides emitted to water as part of the used fountain solution. The biocides used are typically Kathon and bronopol but Kathon may be used alone in a concentration of about 0.06% w/w. In that case the importance of fountain solution is only reduced to 0.9%.

4.1.3.3 Cleaning

Cleaning in the reference scenario is the third most important activity, contributing 305 mPET/fu, corresponding to 17% of the aggregated impact. The main contributors in this case are emissions of hexane and tetradecane where hexane's part is about twice as big as the one for tetradecane. As described in Section 2.1.14 hexane is included to represent a light aliphatic (volatile) cleaning agent whereas tetradecane is included to represent a heavy aliphatic (low volatile) cleaning agent. As can be seen in Table 11 in Section 2.1.14, the mix of cleaning agents chosen for the reference scenario is 2% for surfactants and the rest is shared equally between the heavy aliphatic (tetradecane), the light aliphatic (hexane), the alcohol based (ethanol) and the vegetable based type (soya oil). If for example the aliphatic-based types are fully substituted by vegetable based types (and we assume no content of hazardous components in the substitute like emulgators based on nonyl phenol ethoxylates) the effect is a reduction in the importance of cleaning from 17% to around 0.8%. On the other hand if all but the surfactants (alkoholethoxylate) are substituted by the light aliphatic type (hexane) the effect is an increase to 27% in importance of cleaning in the LCA of sheet fed offset printed matter.

4.1.3.4 Repro, plate making and finishing

In the reference scenario these activities only contribute about 2% each for repro and plate making whereas finishing only contributes about 0.4% to the aggregated impact.

For the repro activity the main contributor is water emission of hydroquinone contributing with around 1.4% whereas the emission of biocides (i.e. Kathone) used in rinse water only contributes around 0.25% of the aggregated impact. Another source of biocide (fungicide) emission is film emulsion emitted to water via the rinse water. Due to scoping and lack of data this potential emission together with potential emission of filter dyes and wetting agents also from film emulsion are not included here and preliminary assessed to be insignificant due to the very low quantity per functional unit (see Section 2.1.1).

For plate making the main contributor is water emission of biocides (i.e. Kathone) in used rinse water contributing about 1.7% whereas the contribution from the use of aluminium plates only contributes 0.24%. For the reference scenario it is assumed that the aluminium plates are fully recycled, i.e. only the 8% loss during recycling is allocated as virgin aluminium to the plate making activity – the rest (92%) is considered as recycled aluminium. If it is assumed that the model printing company uses virgin aluminium exclusively and the potential impact from the production of virgin aluminium is fully allocated to the plate making activity, its importance is increased to about 3.7% of the aggregated impact. In that case the importance of use of aluminium is increased to 1.5% of the aggregated impact.

In the scoping of the finishing process some chemicals and activities are excluded that belong or may be considered as belonging to finishing. Including for example dispersion glue which typically contains biocides (Miljønet 2004) that may be emitted during cleaning with water, UV inks and especially the process of lamination may elevate the importance of finishing in the LCA profile on sheet fed offset printed matter. However this elevation is preliminary assessed not to change the overall LCA profile for printed matter substantially.

4.1.4 Excluded processes

4.1.4.1 Transport

As described in Section 1.1.2.3 on scoping transport is not dealt with as a separate activity in this LCA. Previous LCA studies by Dalheilm & Axelsson (1995), Axelsson et al (1997) and Johansson (2002) which all include transport as a separate entity (transport of raw materials for the production stage and transport during the production stage) indicate that when only energy related impact categories are included transport in the whole life cycle of generic offset printed matter accounts for around 10% of the potential environmental impact. In the study by INFRAS (1998) transport for distribution of newspapers in a newspaper LCA is estimated to account for about 4% of the total environmental load. The LCA study by Frees et al. (2004) on paper production and recycling of paper indicates that transport only accounts for about 4% of the energy consumption for recycling, even though this process involves a lot of transport, i.e. gathering of paper waste from several small industries, transport to one central paper mill for re-pulping etc. Furthermore in the final draft report "Review of existing LCA studies on the recycling and disposal of paper and cardboard" by Villanueva et al (2004) a study by Tillman et al from 1991 is analysed and this study indicates a contribution of 2% from transport to the overall paper cycle energy profile. When the chemical related impact categories are included, as in this study, it is assessed that transport accounts for around 5% of the aggregated impact covering the whole life cycle of the generic sheet fed offset printed matter.

4.1.4.2 Waste

Due to lack of readily available data, the scoping of this study and the method used (EDIP) waste i.e. nuclear waste; chemical waste, bulk waste, and slag and ashes are only treated as total amount (kg, no differentiation by characterisation factors) in this study. However the emissions from, for example, treatment of chemical waste from the printing company and of de-inking sludge from recycling of paper could maybe contribute significantly to the total potential impact of printed matter. Unfortunately it has not been possible to include these issues in this study.

4.2 Conclusion

The goal of this study is to identify the distribution of potential environmental impacts and consumption of resources during the life cycle of generic printed matter produced on a model sheet feed offset printing company. This distribution is represented by LCA-profiles on overall results in the Figure 39 and Figure 40. These results are based on average consumptions and emissions from primarily Scandinavian sheet fed offset printing companies but assessed to be fairly representative for average modern technology in Europe. The functional unit (fu) is one-ton printed matter.

In Figure 39 and Figure 40 the contributions are divided into the different activities at the model printing company, the energy consumption at the model printing company and the contribution from paper production as a net value (avoided potential impact and resource consumption from incineration and recycling of paper is withdrawn). This is primarily done because in ecolabelling we typically focus on the activities at the printing company. Paper is shown separately (though actually a raw material for the printing process) mainly because former LCA studies indicate that it is the overall dominating factor. This study including the chemical related impact categories however indicates that the LCA profile for generic sheet fed offset printed matter is much more varied as shown in Figure 39 and 40.

For aggregated weighted potential environmental impact (hereafter designated aggregated impact) the dominant activity is printing with 41% contribution, see Figure 39. This 41% consists of 18 % from ink emission at the model printing company (e.g. mineral oil components), 17% from upstream pigment production (emission of synthesis chemicals), 6% from emission of IPA at the model printing company and 1% from emission of used fountain solution at the model printing company. Paper contributes 31%, which is mainly due to emissions related to energy consumption (CO_2, SO_2, heavy metals) which is also the case for the 6% contribution from the energy consumption at the model printing company. Cleaning activities at the model printing company contribute 17% where emission of volatile organic aliphatic solvents is dominant. Plate making contributes about 2%, dominated by emission of biocides (used recycled rinse water). Repro activities at the model printing company also contribute about 2% (mainly due to emission of hydroquinone) whereas finishing only contributes about 0.4%.

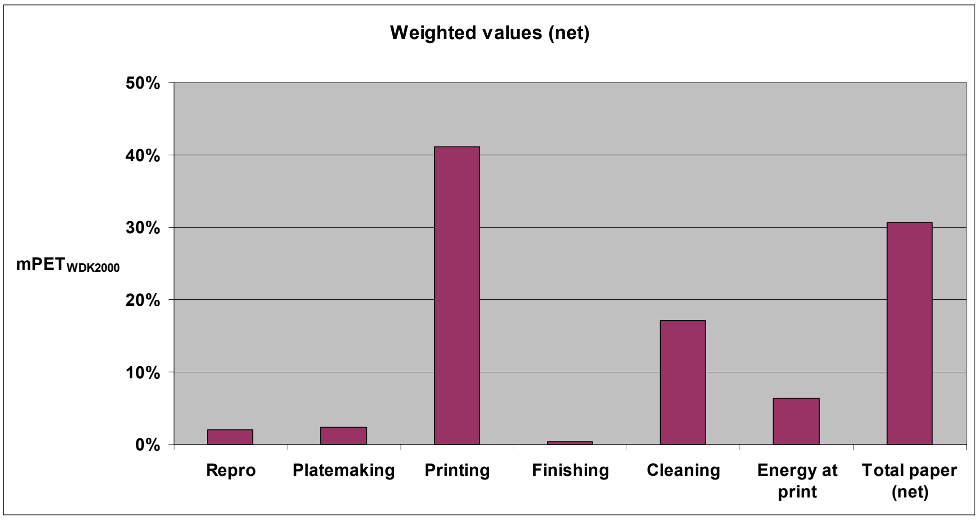


Figure 39. Aggregated impact profile for the reference scenario in relative figures and with total paper as net value.

For the aggregated weighted resource consumption paper is dominant with a share of 48%, primarily due to consumption of energy carriers (natural gas and oil), see Figure 40.

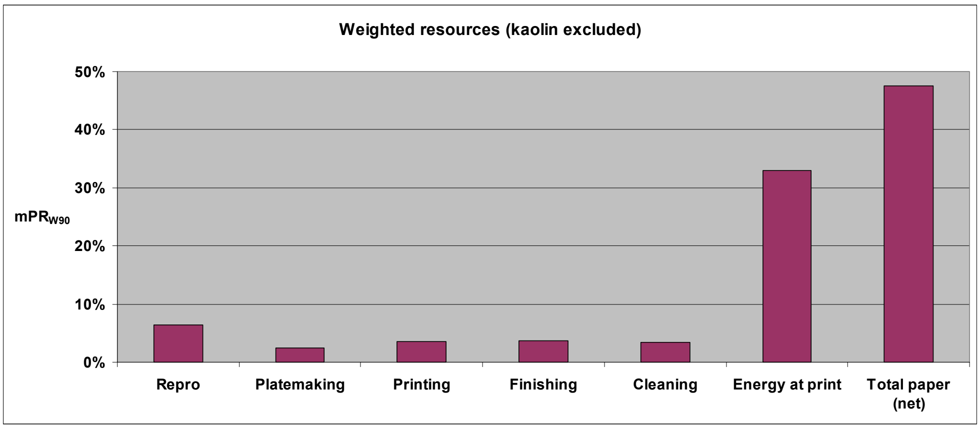


Figure 40. Aggregated weighted resource profile for the reference scenario in relative figures and with total paper as net value and kaolin excluded.

In Figure 40, kaolin (used as filler for paper) is excluded but if it were included the share of paper would be increased to 88%. However kaolin can easily be substituted by, for example, chalk, reducing the importance of the filler by several orders of magnitude. Energy consumption at the model printing company has a share of 33% in Figure 40, which is also mainly due to consumption of energy carriers (natural gas). The repro activity has a share of 6% (silver) and finishing a share of 4% (energy carriers, uranium). For printing the share is also 4% (energy carriers, natural gas) whereas for cleaning it is 3% (energy carriers, uranium) and for plate making 2% (aluminium).

The main results from the sensitivity analysis are the following:

- Using European based normalisation references and weighting factors instead of the Danish/Swedish ones used in the reference scenario does not change the overall LCA-profile significantly
- The inclusion of a European disposal scenario for paper (i.e. including land filling) in the reference scenario is assessed probably not to change the LCA profile substantially
- Known emissions that it has not been possible to include in this study are preliminarily assessed (on the basis of readily available data) probably not to change the overall LCA profile of the reference scenario if included

The results of this LCA study are therefore assessed to be valuable both for ecolabelling of offset printed matter (especially sheet fed) on a Nordic scale (Swan labelling) and a European scale (Flower labelling).

Further sensitivity analysis and alternative scenarios performed by varying the consumption, emissions etc. within the observed and estimated ranges at the model printing company give the following main results:

- The effect of treating waste water from the model printing company in a waste water treatment plant including a biological step is a reduction of about 26% in aggregated impact
- The effect of reducing the printing ink consumption from 26.5 kg/fu to 1.8 kg/fu is a reduction in the aggregated impact of 56%
- The effect of substituting the biocide benzalkonium with the biocide Kathon (both used for preservation of rinse water) is a reduction in the aggregated impact of 69% (no waste water treatment included)

- The effect of using recycled paper exclusively instead of virgin paper exclusively is a reduction in the aggregated impact of 16%
- The difference between using highly volatile aliphatic cleaning agents instead of vegetable oil based types may be 27% contribution to the aggregated impact instead of 0.8%

As illustrated by the points mentioned above, the strength of this LCA approach for use in ecolabelling of printed matter is not only the exact LCA profile of the reference scenario based upon average values but to a high degree the possibilities to use sensitivity analysis based upon known or theoretical ranges within values on consumption, emissions or other parameters. By conducting sensitivity analysis we see an indication on how sensitive the distribution of the potential impact within the life cycle of the printed matter is to variation in the parameter in question and thereby guidance on how much weight to put on the parameter in the development of ecolabelling criteria based on a life cycle approach. This LCA approach is also valuable when dealing with substitution, i.e. substituting one chemical with another technically suitable type and observing the change in the distribution of the potential impact within the life cycle.

The main issues that it has not been possible to include in this study and that might change the outcome significantly include:

- Upstream emissions of specific substances, e.g. emission of synthesis chemicals from pigment production based on measured values (included in this study but based on estimated values)
- Fate of paper when disposed as land fill, i.e. how much methane is actually emitted to air?
- Fate of chemical waste and other waste types from the printing company etc., e.g. how big is the potential environmental impact from treatment of used solvent or rinse water from printing or waste treatment of deinking sludge from recycling of paper?

Research in these areas is needed if the reliability of the LCA on printed matter is to be further strengthened and thus improving the foundation for life cycle based ecolabelling criteria for printed matter

5 Critical review

A critical review by the external expert Kim Christiansen, 2.-0 LCA Consultants (kc@lca-net.com) has been conducted. The review report is shown below with the authors' comments in italics.

The review has focused on the correctness and completeness of the summary and conclusions versus the body text of the report as well as the overall quality of the methods and data applied, especially the use of average and marginal data. The critical review statement is structured according to the requirements of the ISO 14040-series; although detailed comments are, placed under section 5.1.4.

5.1 Result of the critical review

Overall a well-presented study structured according to the phases of an LCA study. The assumptions and underlying calculations are presented in reasonable detail, and the limitations well discussed. This gives the impression that the results are robust, or at least, as robust as possible given the limitations at hand.

The LCA study is intended to be used for criteria and methodology development within ecolabelling of printed matter (Preface, page 5) i.e. the results will be disclosed to the public. According to ISO 14040 therefore a panel of interested parties shall conduct the critical review. The status of the report for the present critical review by an external expert is therefore assessed to be for internal use only. It is recommended to involve the steering group formally in the critical review process in the finalization of the study report.

The members of the steering committee representing interested parties have had the drafted final report for review. Furthermore, comments, inputs etc. from the steering committee have currently been included in the study (see Preface).

The report does not make reference to the ISO 14040-series. Therefore, formally, the requirements of the ISO 14040-series do not apply. Nevertheless, the study and the report are clearly structured according to the framework and guidelines of the ISO standards, and the EDIP methodology applied in the study (page 19) is also announced as fulfilling the requirements of the ISO 14040-series. Similarly, at better introduction to attributional and consequential LCA could be included, as both average and marginal data are used in the study (which will impact the conclusions on e.g. scenario 2).

A reference to the ISO 14040-series has been added (see Introduction). A better introduction to attributional ("average") and consequential ("marginal") LCA is not included. The use of average data in the reference scenario for the processes (technology, consumptions and emissions) at the model printing company is deliberately chosen because we want to reflect an average situation. For most of these processes or factors the printing company has at least to some degree a choice, i.e. these factors are steerable. For consumption of electricity there is no choice and the use of marginal data is therefore more relevant. Besides we want to avoid the site-specific variations in potential impact from electricity production in this LCA study.

5.1.1 Methodology

Focusing on the manufacturing (production) of the final printed matter can be justified, but it is not per se a requirement for ecolabelling; actually, environmental impacts from e.g. paper production within the impact categories of toxicity and eco-toxicity could be of higher importance than found, if a similar detailed approach was applied.

A similar detailed approach for upstream processes has not been possible to use because of lack of data and the resource scoping of the study. However, this issue is discussed extensively in the report and the conclusion based on existing knowledge is that inclusion of upstream emissions to a higher degree probably would not change the overall result of this study, see for example Section 3.2 (chemicals in general) and Section 4.1.3.1 (AOX). Furthermore, besides AOX, the other group of potentially most significant contributing emissions from paper production, i.e. emissions of metals to water, is actually included in the life cycle impact assessment:

AOX	*107g Cl/fu*
Arsenic	*0.023 g As/fu*
Manganese	*0.44 g Mn/fu*
Strontium	*48 g Sr/fu*
Copper	*0.19 g Cu/fu*
Mercury	*0.00093 g Hg/fu*
Cadmium	*0.023 g Cd/fu*
Zinc	*2.3 g Zn/fu*
Nickel	*0.19 g Ni/fu*
Selenium	*0.0060 g Se/fu*
Lead	*0.098 g Pb/fu*

A weak point is that the framing of the problem could have been stronger, particularly with defining a meaningful reference scenario, and in structuring the subsequent scenario inventories and the sensitivity analysis. Both the use of scenarios and the "sensitivity analysis" included in the study are approaches to test the robustness of the scoping of the study; the procedure outlined in ISO 14043 could be used to make this more clear. Choice of scenarios should be based on both what is thought relevant based on earlier studies and on iteration with the inventory analysis and the impact assessment; it is not very clear if this is the case in the present study.

The choice of the scenarios is actually based on what is thought to be relevant based on earlier studies (e.g. paper, scenario 2 and scenario 3) and on what came up in the first, second and third iteration (e.g. biocides, scenario 6 and ink consumption, scenario 4). The choice of the scenarios based on the iterations was discussed within the steering committee. The purpose of the scenarios in this study is to indicate the importance of a certain parameter (e.g. ink consumption) for the impact profile of printed matter when this parameter is varied within a range representing what can be observed within the printing industry today (e.g. 1.8 kg ink/fu – 26.5 kg ink/fu). This is very important information when dealing with ecolabelling criteria based on a life cycle perspective. The main purpose of the sensitivity analysis in this study is to analyse the robustness of the reference scenario (main scenario – based on average values for consumptions and emissions) by for example using alternative normalisation references/weighting factors and alternative allocation principles for paper. However the variation in parameters (e.g. type of cleaning agent used) is also covered in the sensitivity analysis. So some of the results from the sensitivity analysis can both be used for the robustness evaluation of *the reference scenario and when finding out which weight to put on a certain parameter when developing ecolabelling criteria on printed matter.*

Furthermore, the choices made in defining the reference scenario are somewhat inconsistent, notably that the marginal technology is used for electricity and paper production, but not in the printing technology chosen, and that transport is only partly included. The use of an average printing process should be clearly placed with respect to best/worst performance and the marginal technology. Intending to apply the results for ecolabelling but excluding new technologies within e.g. the printing company is not justified as market shares are increasing (page 33).

The consequences of using average energy data for electricity production is shown in scenario 1. Transport is only partly and implicitly included but the importance of transport is assessed on the basis of several former studies, see Section 4.1.4.1. As pointed out above, the use of average data in the reference scenario for the processes at the model printing company is deliberately chosen because we want to reflect an average situation. The results of this study are to be used as a basis for ecolabelling in Scandinavia and Europe using average technology as a starting point. The effect of using BAT (Best Available Technology) is at least to some degree reflected in the scenarios run by varying parameters within observed ranges (e.g. paper spillage, scenario 3) but focusing explicitly on BAT technology is not within the scope of this study although the framework used here could easily be used in such a study.

The choice of impact assessment categories (not "criteria", page 19), time scope and use of marginal versus average data (not "approaches") is not very well justified (explain why and how). "Waste water treatment" encompasses a major variation in technology and performance; using geographic arguments for including or not including this process is not justifiable. The scope definition of choosing a 1 year life time for the product examples depicted is not justified (page 30 and 32). In fact, the reference scenario is not 1 scenario (modeled product system) but actually several e.g. with or without WWT, with or without avoided energy consumption and avoided emissions from incineration and recycling of paper etc.

The choice of assessment criteria is justified, see Section 1.1.2.2. The choice of marginal versus average data is commented above. The inclusion of generic wastewater treatment (WWT) with a biological step is justified in Section 2.4.5. However including the variation in technology and performance of WWT is not within the scope of this study. The choice of one year as product life time is assessed to best represent the average of the different printed matter types by sheet fed offset (Bøg, 2003) but is also chosen for the sake of normalization of the LCA results, see Section 1.1.2.1.The reference scenario is actually one well defined scenario (see Section 2.4) for example it is without WWT, and avoided energy consumption and avoided emissions from incineration and recycling of paper is allocated to paper. However, results are shown in different variations to inform the reader, and whenever variations are included it is pointed out, for example by marking paper with gross instead of net (reference scenario) indicating that avoided energy consumption and avoided emissions from incineration and recycling of paper are not allocated to paper in the actual situation.

The choice of energy scenario is shown to be very important, so the choice of gas for marginal technology may need to be more robustly defended. Also, scenario 7, "no waste water emitted" is not meaningful; if no waste water is discharged, there will be sludge from the internal WWTP, but the sludge disposal process is not included.

The choice of natural gas for marginal technology is documented in Frees et al. (2004). As pointed out several times in the report (e.g. Section 4.1.4.2. and Section 4.2) the treatment processes of chemical waste have not been possible to include in this study due to data lack and resource scoping. Furthermore, it is pointed out (see Section 4.2) that the inclusion of treatment of chemical waste will increase the liability of this LCA study. However for waste water it is preliminarily assessed that treating the waste water as chemical waste under controlled conditions will give rise to a significantly lower potential impact than emitting the waste water directly to the water recipient.

The normalisation factors used in the study increase the importance of toxicity impacts relative to the other impacts considered (and they are also given a higher weight than the other impacts when calculating the overall load). Thus there is a danger that the major conclusion of the study (that the printing process is as important, or more important, than the paper input) may be somewhat due to the methods chosen (or at least that the methods and conclusions are self reinforcing). In exploring the sensitivity of the system to normalisation and weighting, it is recommended to use different weighting (value) methods and to show the consequences for the results of these value choices (e.g. Ecoindicator99).

The effect of using other normalisation references and weighting factors for the EDIP method is tested by introducing updated factors and factors covering Europe, see Section 4.1.1. The effect of introducing European factors instead of Danish ones does not significantly change the overall result of the study. Furthermore, a scenario where the chemical related impact categories (ecotoxicity and human toxicity) are excluded is compared to previous studies on offset printed matter based on both EDIP, Ecoindicator95, CML and CPM, in which chemical emissions are only included to a limited degree or not at all. The result of this comparison shows that if the chemical related impact categories are excluded from the reference scenario, the importance of paper is increased to the same level as shown in the previous studies (about 70%), see Section 4.1.3.1. Due to resource scoping of the study, inclusion of other impact assessment methods has not been possible. Besides, using Ecoindicator99 in this chemical dominated LCA study would most probably be insufficient because only a limited number of characterisation factors are available for ecotoxicity (40 - 50) and sufficient data for calculating new ones does not exist in most cases. Furthermore, the way to do the calculations is not fully transparently described and the underlying models are not available to the LCA practitioner.

The interpretation phase of an LCA is used to make the conclusions, and the sensitivity etc. of the conclusions is tested. The overall uncertainty and sensitivity of e.g. the inventory analysis and the impact assessment should be conducted as part of these phases. However, the rational for the choice of data sources and the use of data quality indicators is not included in the study; and this should be justified.

The data quality indicators are not described separately in this study but the quality of the data which is used is indicated in the presentation of the data, for example the composition of the raw materials presented in Section 2 can be either based on newly updated data sheets from producers, personal communication with producers or secondary sources like literature published 10 years ago.

The sensitivity analyses based on the different scenario variations to the basic scenario could be structured in a more systematic way. In particular, it would be valuable to know what the data ranges presented in Table 12 represent, e.g. best technology, worst technology, and where the marginal technology lies in the range. This is especially important for those variables found to change the results to such a very significant extent (e.g. ink consumption, alternative biocide agent).

The data in Table 12 is expected to represent ranges covering from worst technology (worst technique/bad house keeping) to best technology (state of the art) but this is not specified in the main part of the documentation. The marginal technology is not known in all cases and defining it has not been within the scope of this study.

5.1.2 Data

"Readily available data" from different sources are used and as stated with different functional units (page 19). This is a serious flaw in the data quality. The ranges depicted on the original data, could be interpreted as making the data non-applicable in the development of ecolabelling criteria.

Different functional units are not used – all data are normalized to the functional unit: 1 ton sheet fed offset printed matter. The ranges within the data are reflecting the actual situation in the printing industry from about 1990 to 2002. Using the average for the reference scenario and the ranges in the alternative scenarios/sensitivity analysis actually makes these data very valuable for developing ecolabelling criteria on printed matter.

Data in e.g. Seedorf et al. (1993) and Boethling (1984) are out of the time scope of the study. This is not discussed or justified.

Seedorf et al. (1993) is not used alone but only for confirmation of data from 2000, 2001 and 2002 from producers of film developer and film fixer, see Section 2.1.2 and 2.1.3. Boethling (1984) is used for documentation of biodegradation of benzalkonium chloride in wastewater treatment plants with a biological step, as this reference is the most relevant for this type of substance.

Data sources and actual primary data of the inventory data (categories) are listed in the appendices but the "raw" spreadsheet format, the mixed use of English and Danish terms and the limited introduction to each annex makes it difficult to benefit from the inclusion of the data.

Annex B has been restructured and Danish terms in Annex C has been translated to English.

The inventory data should be presented disaggregated according to the major processes and life cycle stages in the report – including the variation of the data and other data quality indicators - and not just presented aggregated in Annex C. Table 17 does not show, which stages are most important as referenced in the summary (page 22).

In order to restrict the size of the report it has been chosen only to present the aggregated results for the LCA in Annex C. The relevant disaggregated results are described mainly in the text of the report. The most important stages related to Table 17 are extensively described in the text in Section 3.

Table 12 includes the ranges but these are not propagated into the inventory of the processes. Also, the range of data depicted in Annex B is not used as uncertainty indications (ranges) in Annex C.

The most important ranges are used in the different scenarios and sensitivity analysis. The ranges depicted in Table 12 (last column from the left) are based on the data in Annex B.

The precision of the data is over-reported e.g. the percentage of ink disposed of as chemical waste – 19.6% if a very exact figure based on a range of 2.4-45.9% and the calculation is not included (page 34). What is the range (lowest reported value and highest reported value or a normal-distribution or...)? This comment is relevant for many other data included e.g. scenario 3: Spillage of exactly 32.1% versus 3.3% (page 35).

The reporting of data precision in the report has been revised in some cases. The data used for calculating the average and the range shown in Table 12 (last column from the left) and for example the ink disposed as chemical waste is shown in Annex B.

Also, the mere size of figures 2, 3, 4, 5, and 6 makes them difficult to read; a table with the data should be included showing the impact contributions of the specific processes or life cycle stages included in the study. This comment is also relevant for many other figures of the report, which are not easy or impossible to read; tables should be included e.g. in annexes with the specific data of the impact assessment results.

The exact data on which the shown figures are based are to a very high degree given in the text of the report.

Figure 10 seems to be the most correct figure for presenting the aggregated and weighted results on a process level. The conclusion of the summary should be based on this.

This is not done because the starting point for the development of ecolabelling criteria is the processes occurring at the printing company, and only paper and energy use at the printing company are shown separately because special focus is already paid to these. However a differentiation of processes into upstream and downstream activities is discussed and shown graphically (e.g. Figure 10) in the report.

The use of electricity and (district) heating in the printing process presented at page 66 should be in a table with the variations included, which will improve readability.

The data are already given in the text.

The presentation of the data sources (or inventory data sources) in Annex A should include not only the reference but also the representativeness etc. – the data quality indicators – of each source. Some sources are identified by author(s) other by name of consulting firm and other by title of publication; this inconsistency should be remedied. Also, a few of the referenced primary data sources lack the year of the publication e.g. 1.2.4 Ammonia, or the primary data source is not referenced e.g. hot melt glue. Sometimes abbreviations are used which are not likely to be known by the reader e.g. COWI-NBE.

Annex A has been revised where reasonably possible within the resource scoping of this study.

Data for recycling of paper can be found in "Returpapirstatistikken" – reading a graph in a publication for the general public from the Danish EPA is not convincing. The calculation of the recovery rate should be included in the report, not in an annex listing data sources. This is also the case for the energy recovery assumption – and who is assuming?

The primary data source for the recycling of paper has been included.

A very small detail, but: "dk-Teknik" should be dk-TEKNIK ENERGY & ENVIRONMENT (now FORCE TECHNOLOGY...); MGR is Morten Grinderslev.

Has been erased

5.1.3 Interpretation

The most significant finding of the study (i.e. the large contribution by the printing process to the overall environmental load when toxicity is taken into effect) might be an artefact of having a more detailed inventory list for printing than the other processes in the life cycle (e.g. paper) - a more detailed inventory with more substances contributing to the overall environmental load will show an increased load relative to processes with a less complete inventory. Also, paper is still the most important contributor to the weighted overall environmental impact – although there is no discussion on the significance of the difference between 48% for paper (production!) and 41% for printing (process). This changes if the recycling of paper and heat recovery is taken into consideration (31% and 41%, respectively), which would a more correct result to report, but the most correct would be with the upstream ink-production as a separate process – as in figure 10 – i.e. this figure should be presented first and then the others as different types of aggregation of this.

These issues are already commented above. However, the fact that paper gross has an importance of 48% is shown in Figure 8, and alternative allocations for paper production are discussed in Section 4.1.2.

The credits of recycling, i.e. avoiding production of virgin paper and of heat recovery, are assigned to the "paper" processes which for the comparison of paper production and recycling with printing is justified, although assignment of the credit of recycling paper to the user of the printed matter delivering it to recycling would be more methodologically correct.

Assigning the credit for recycling of paper to the user would be meaningless in this context.

Adding to this are the inconsistencies in the inventory data, e.g. COD, VOC do not have equivalency factors in the method used, and so are not included in the impact assessment, which adds to the uncertainty of the result having only 33% and 26% of the substances emitted to air and 25% and 37% of the substances discharged to water characterized to toxicity and ecotoxicity, respectively (page 21); the adjustment of these percentages by excluding substances not contributing is valuable and could be included as a more correct expression of the coverage, but it is still only around 50%. (Both calculations are based on quantities, I assume?).

VOC actually has characterisation factors (equivalency factors) but only for photochemical ozone formation. COD is not contributing to any of the impact categories considered in the study but may contain substances which would be ecotoxic. Inclusion would require a specification of the substance content underlying the COD. As described in Section 3.2 the referred 33%, 26%, 25% and 37% are all based on *numbers of substances - not the emitted quantity. The referred around 50% (actually 48% for human toxicity and 53% for ecotoxicity) is based on quantity as also described in Section 3.2. Coverage of 48% - 64% (based on quantities and excluding non contributing substances) for human toxicity and ecotoxicity, as is the case in this study, is probably at the level off what is achievable with the knowledge of today.*

Also, consequences of not having data on e.g. siccatives and softeners should be discussed – not just referenced as likely significant contributors, and the rough estimate on the importance of AOX emissions from paper production should be made available in the report – especially in view of the importance of acute and persistent ecotoxicity (page 22 and 24).

The consequences of not having data on siccatives, softeners etc. and the importance of AOX emissions are actually discussed, see Section 3.3 and Section 4.1.3.1.

Presentation of the impact assessment results by bar diagrams should be supplemented by tables with the figures and the variation (uncertainty) of the results included. The results depicted in e.g. figure 3 (page 60) adds little value to the interpretation – it's not easy to read, and no indications of the significance of the differences are included. Also the legend should indicate that the paper production, recycling and incineration are excluded, not just paper.

It has been chosen as form of presentation not to include tables with the figures shown in the graphs but to describe and discuss the results in the text. That the paper net value is used in Figure 3 is described in the figure text.

In the summary, references to the scenarios as well as the wording of the scenarios should be consequent (e.g. that waste paper is paper spillage in production, that WWTP is scenario 5, and that substituting the biocide is scenario 6). Also, the scenarios should be better presented in the summary (as this is already lengthy).

Is corrected except for the degree to with the scenarios are presented in the Summary and conclusions which is maintained because it is assessed to be in balance with the degree to which other issues are represented.

The lack of data on waste and the ability to differentiate between the impacts of different waste types is a drawback of the study results in itself, as stated for land filled paper waste and treatment of chemical waste (page 27), but furthermore the waste treatment processes should be included in an LCA study; this should be added as a comment in the summary (page 26 or 27).

The sentence that "the waste treatment processes should be included in an LCA study" is included. The issue of the degree to with waste is included in the study and the consequences thereof are discussed and described in several sections of the report, e.g. Section 1.1.2.2, Section 1.1.2.7 and Section 4.1.4.2.

The conclusion on the applicability of the data for offset printed matter in general seems to be robust based on the comparison with Drivsholm et al. (page 72f) within the scope of the study, but as indicated above, this scope can be questioned.

See comments on scoping above.

5.1.4 Report

The structuring of the report might be improved by using the outline of the ISO 14040-series more consequently. Also the hierarchy of the headings does not seem logical in size and form, but this might be due to reporting requirements of the Danish EPA:

The conclusion of the summary should be in an abstract; the interpretation phase of the LCA results in the conclusion as such – or it is the conclusion. Having conclusion in both the summary and the interpretation is somewhat confusing and at least redundant, although present text is not exactly copied.

The conclusion is included in the "Summary and conclusions" because it is a stand-alone section.

The language is sometimes un-precise e.g. "generic" could be interpreted as covering all types of sheet fed offset printed matter and similarly, the term "fictitious" sheet fed printing company could be interpreted as not being based on real-world information and data and focusing only on the manufacturing of the printed matter. It is recommended to change the wording, including the title, e.g. "Life cycle assessment of model off-set sheet printed matter".

Fictitious has been substituted by model

Paper gross and paper net should be explained in the summary as well, e.g. by footnotes. Also, the different printing processes and printed matter products could be better presented; this would be especially valuable for the comparison with the study by Drivsholm et al.

Paper gross and paper net is actually explained in the "Summary and conclusion", see Section "Goal and scope definition".

References should be included in table and figure text (e.g. table 3 and 4).

This would make the figure text two large in some cases and is not done. The references are described in the text refereeing to the figures.

Legends are missing in Figure 1 (e.g. what is EU TGD?).

Figure 1 is revised

A few references are missing in the reference list (Eurostat, 2002; Tillmann et al., 1991; and those given as references within references e.g. von Däniken A and Chudacoff M, 1995; Franke et al., 1995; Boustead, 1993; Christensen, 1991). Use of indirect references omits the option of a preliminary judgment on the data quality by knowing the primary source.

Use of references is revised.

The "anonymous" references should be clarified (personal communication, plant data, in-house report).

Further clarification not possible

The headings of the appendices should be included in the list of contents (page 4).

Is done

Annex B includes data representing the processes of the model-manufacturing site, not the "inventory process" – the annex is not depicting an overview of the process of doing the inventory! Annex B is also not sufficiently documented. The two parts of the annex should be separated i.e. the model printing site and the data of the 11 real-world printing sites. Also the columns of the latter could include the age of the data and other data quality requirements – and be organised according to the introductory text of the annex! The few headings in Danish should be translated.

Annex B has been revised where reasonably possible within the resource scoping of this study.

In Annex C the use of kg and g is inconsistent. Also some names and units are missing for some of the entries (data categories) in the resources list. The use of names in Danish of e.g. the different waste types makes it difficult for a non-Danish reader to find the relevant data.

Annex C has been revised where reasonably possible within the resource scoping of this study.

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Wenzel,H., Hauschild, M., & Alting, L. (1997) Environmental Assessment of Products, Vol. 1. First edn. Chapman & Hall

Inventory sources

The inventory sources are described below. For the material stage the main processes, i.e. forestry, pulp and paper production, agriculture, extraction and refining of oil, water and electricity are described separately. The other processes in the material stage are described in connection with the description for the activities at the printing company, repro, plate making etc.

6.1 Material stage

6.1.1 Forestry

Data is available in EDIP LCV tool: M32378 (Miljøstyrelsen 1999).

6.1.2 Pulp and Paper production

Data from project (Frees et al. 2004). Original data is EMAS reports from Swedish factories in the Stora Enso Corporation covering main use of energy and materials and emission of primary compounds mainly from energy consumption and data from Skogsindustrierna in Sweden yielding mainly emissions of heavy metals.

6.1.3 Agriculture (Soybeans)

Generic data from: *Vergleichende ökologische Bewertung von Anstrichstoffen im Baubereich BUWAL, Schriftenreihe Umwelt Nr. 232, 1995.*

6.1.4 Extraction and refining of oil

The extraction and refining of oil are not included as separate processes in this study as the process is covered by cradle-to-gate data on production of chemicals and other intermediates.

6.1.5 Water

Production data of water from water works is available in the EDIP tool (Miljøstyrelsen 1999).

6.1.6 Electricity

Marginal and average approach

6.1.6.1 Marginal approach

Data is available in EDIP LCV tool: CC-ELK-NF02 (Miljøstyrelsen 1999). Data from “Energi E2”, which is a Danish producer of electricity. Revised by Niels Frees, IPU

Also described in Frees et al. (2004)

6.1.6.2 Average approach

Data is available in EDIP LCV tool: Swedish electricity (1990): IPU-NF-L2748T01; Danish electricity (1997): IPU-NF-LSYS100 (Miljøstyrelsen 1999).

6.2 Production stage

6.2.1 Repro

Film, repro: Material Safety Data Sheet from Kodak giving the material "Estar". Available at www.kodak.com. The material Estar is PET (Lapp et al. 2000). KODAK (2001a), Baumann & Gräfen (1999a), APR (2003)

Silver and halides: Emission Scenario Document (p. 26). Photographic industry, IC10. Assessment of the environmental release of photochemicals (Baumann & Gräfen 1999a)

Film developer (KODAK RA2000): Material Safety Data Sheet from Kodak available at www.kodak.com. (KODAK 2001b, 2003)

Film fixer (KODAK RA3000): Material Safety Data Sheet from Kodak available at www.kodak.com. (KODAK 2000, 2003)

Biocides: Kjærgaard (1997), Larsen et al. (1995, 2002), Andersen et al. (1999), Gruvmark (2004), Deltagraph (1997)

Process water: Data about Danish water works is available in the EDIP LCV tool: K32506 (Miljøstyrelsen 1999).

6.2.2 Plate making

Aluminium plate: Production of aluminium from *European Aluminium Association (2000). Environmental Profile Report for the European Aluminium Industry* Available on request at the web page of the Europen Aluminium Association at www.aluminium.org"

Plate emulsion: Larsen et al. (1995), Baumann & Gräfen (1999b), Muskopf (2000), Baumann & Rothardt (1999), Ludwiszewska (1992) and KODAK 2002a)

Plate developer: (Larsen et al. 1995).

Gumming agent: (Larsen et al. 1995) and (Agfa 2002).

Biocide: See Repro.

Remelting of aluminium: See Aluminium plate

Process water: See Repro

6.2.3 Printing

IPA: Personal communication with Ian Kersey, BP Chemicals, 2003 (confidential)

Printing ink
Composition: Larsen et al. (1995)

CI pigment yellow 14 and CI pigment blue 15: (Andersen & Nikolajsen 2003).

Carbon black: SimaPro version 5.1 (2002). PRé Consultants, Amersfoort, The Netherlands. Available at internet at www.pre.nl. Original reference here "Emissieregistratie process 1532 (1993)". Elaborating information is available in SimaPro: Data is from the Dutch bureau of emission registrations (emissieregistratie). Data is generated by Delft University of Technology. As a comment is mentioned "Environmental assessment for the production of carbon black in the Netherlands. Average data for 1993".

Modified phenolic resin and soya oil alkyd: Data available in EDIP LCV tool (Miljøstyrelsen 1999).

Soya oil:
von Däniken A, Chudacoff M (1995). Vergleichende ökologische Bewertung von Anstrichstoffen im Baubereich. Band 2: Daten. Schriftenreihe Umwelt nr. 232. Bern: Bundesamt für Umwelt, Wald und Landschaft (BUWAL).

n-parraffin (heavy): Franke et. al. 1995. A Life Cycle Inventory for the Production of Petrochemical Intermediates in Europe. Tenside Surf. Det. 32 (1995) 5.

Polyethylene wax. See water based lacquer

Diethylene glycol: von Däniken A, Chudacoff M (1995). Vergleichende ökologische Bewertung von Anstrichstoffen im Baubereich. Band 2: Daten. Schriftenreihe Umwelt nr. 232. Bern: Bundesamt für Umwelt, Wald und Landschaft (BUWAL).

6.2.4 Finishing

Water based lacquer:
Ethanol: Personal communication with Ian Kersey, BP Chemicals, 1995 (confidential)

Ammonia: Production data in EDIP tool (Miljøstyrelsen 1999): Primary reference is: *European Fertilizer Manufacturers Association (1995): Production of Ammonia. Booklet no. 1.*

Polyethylene wax: Production data in EDIP tool (Miljøstyrelsen 1999): Primary source is LDPE from *Vergleichende ökologische Bewertung von Anstrichstoffen im Baubereich BUWAL, Schriftenreihe Umwelt Nr. 232, 1995.*

Alcoholethoxylate: Production data with 7EO chains from: *Dall'Acqua, S., Fawer, M., Fritschi, R., Allenspach, C. (1999): Life Cycle Inventories for the Production of Detergent Ingredients. EMPA-Bericht Nr. 244. St. Gallen, 1999.*

Acrylic resin: Production data in EDIP tool Miljøstyrelsen (1999): Primary reference is *Vergleichende ökologische Bewertung von Anstrichstoffen im Baubereich BUWAL, Schriftenreihe Umwelt Nr. 232, 1995.* Data and energy scenarios are revised by Niels Frees, IPU.

Offset lacquer:
See printing ink (excluding pigments)

Hotmelt glue: Composition from: Miljønet (2004).

EVA: LDPE is main ingredient in EVA according to (Schmidt et al. 1993) and is used as production data.

LDPE: Boustead, I (2003). Eco-profiles of the European plastics industry. Polyolefins. APME, Brussels.

Phenolic formaldehyde resin: Miljøstyrelsen (1999): EDIP tool. “Alkyd bindemiddel” used as model for production.

Polyethylene wax. See water based lacquer

6.2.5 Cleaning

Soya oil: von Däniken A, Chudacoff M (1995). Vergleichende ökologische Bewertung von Anstrichstoffen im Baubereich. Band 2: Daten. Schriftenreihe Umwelt nr. 232. Bern: Bundesamt für Umwelt, Wald und Landschaft (BUWAL).

n-paraffines: Franke et. al. 1995. A Life Cycle Inventory for the Production of Petrochemical Intermediates in Europe. Tenside Surf. Det. 32 (1995) 5.

"Ekstraktionsbenzin": Hansen & Gregersen (1986)

Benzene: Franke et. al. 1995. A Life Cycle Inventory for the Production of Petrochemical Intermediates in Europe. Tenside Surf. Det. 32 (1995) 5.

Ethanol: Personal communication with Ian Kersey, BP Chemicals, 1995 (confidential)

Alcoholethoxylate: See water based lacquer

Process water: See Repro

6.3 Energy consumption at printing industry

Electricity consumption: Data is available in EDIP LCV tool (Miljøstyrelsen 1999): Data from “Energi E2”, which is a Danish producer of electricity. Revised by Niels Frees, IPU.

District heating: Data is available in EDIP LCV tool (Miljøstyrelsen 1999): Data from “Energi E2” revised by Niels Frees, IPU.

Heating with fuel oil:
Data is available in EDIP LCV tool (Miljøstyrelsen 1999)

Heating with natural gas:
Data is available in EDIP LCV tool (Miljøstyrelsen 1999)

6.4 Recovery/Disposal

Amount of paper for recycling: Tønning (2002)

Recovery of paper: In Frees et. al. (2004) a process is constructed via information from a Danish company recycling offset paper. Recovery process is per kg output. In Frees et al. (2004) recovery to "cycluspapir" which is a fine quality printing paper based on recycled paper: Input: 116kg. Output: 97kg. 97/116=83,6%, hence in database 0,836kg of paper recovery process and avoided production of paper is included per kg of paper sent to recovery.

Paper production from primary materials is used as avoided production.

Incineration of paper: Data is available in EDIP LCV tool (Miljøstyrelsen 1999)

An energy recovery of 78% is assumed. The energy recovered is assumed to replace an equivalent amount of energy from primary fuel, which is natural gas in the marginal electricity scenario.

Incineration of PET film: Data is available in EDIP LCV tool (Miljøstyrelsen 1999)

Data on model and real world printing companies

6.5 Data on model sheet fed offset printing Company

The inventory data used for the production (and upstream) at the model sheet fed offset printing company (reference scenario) is shown in the tables below. The data are all related to one functional unit (1 ton generic sheet fed offset printed matter). The tables show consumption, emissions and the composition of the raw materials. Data used in alternative scenarios are marked with colours, i.e. scenario 6, alternative biocide (pastel green) and scenario 5, wastewater treatment included (light yellow).

						Emissions and waste handling														
1 ton generic sheet fed offset printed matter (fu)						**-to air**		**-to ww**		**-chem.waste**		**-recycling**		**vol.waste**		**-incineration**				
Piece	**Repro (per fu)**																			
5,63	**m2**	**Film, Repro**																		
	0,137	kg	PET		*89%*											0,77	kg			
	0,01	kg	Ag		*6%*			2,4E-04	kg			0,0561	kg							
	0,007	kg	Br		*5%*															
2,85	**kg**	**Film developer**						**4,2%**				**95,8%**								
	0,91	kg	Water					0,10805	kg			2,485	kg							
	0,035	kg	Potassium sulfite					0,00419	kg			0,096	kg		WW redist			New values		
	0,020	kg	Diethylene glycol					0,0023957	kg			0,0551	kg		soil	air	wat	soil	air	water
	0,018	kg	Hydroquinon					0,00210	kg			0,048	kg		0%	0%	33%	0	0	0,000692
	0,0076	kg	Sodium sulphite					0,00090	kg			0,021	kg							
	0,0076	kg	Potassium carbonate					0,00090	kg			0,021	kg							
	0,0025	kg	4-hydroxymethyl-4-methyl-1-phenyl-3-pyrazolidinone					0,00030	kg			0,007	kg							
3,17	**kg**	**Fixer**						**18,6%**				**81,4%**								
	0,81	kg	Water					0,48	kg			2,09655	kg							
	0,14	kg	Ammonium thiosulfate					0,082	kg			0,3579	kg							
	0,026	kg	Sodium acetate					0,016	kg			0,06817	kg							
	0,0066	kg	Boric acid					0,0039	kg			0,01704	kg							
	0,0066	kg	Ammonium sulfite					0,0039	kg			0,01704	kg							
	0,0066	kg	Acetic acid					0,0039	kg			0,01704	kg							
	0,0033	kg	Sodium bisulfite					0,0019	kg			0,00852	kg		WW redist			New values		
0,00019	**kg**	**Biocide**						**100%**							soil	air	wat	soil	air	water
	0,25	kg	2-methyl-3-isothiazolon					0,00005	kg						0%	0%	59%	0	0	2,83E-05
	0,75	kg	5-chlor-2-methyl-3-isothiazolon					0,00014	kg						0%	0%	59%	0	0	8,5E-05
								10%												
0,0288	**kg**	**Alternative biocid (benzalkoniumchloride)**						0,00288	kg	25,7g(soil)										
5,77	**kg**	**Water for rinsing**																		
0,77	**kg**	**Incineration of PET**																		
Piece	**Platemaking (per fu)**					Chemical waste sum				5,43E-01	kg									
4,16	**m2**	**Plate for printing of offset product**																		
	0,90	kg	Aluminium									3,44	kg	0,30	kg					
0,000	**kg**	**Plate emulsion**						**24%**		**36%**						**40%**				
	0,01	kg	2-diazo-1(2H)-naphthalinon-derivative					0,0E+00	kg	0,0E+00	kg									
	0,34	kg	Polyvinylalcohol					0,0E+00	kg	0,0E+00	kg									
	0,64	kg	Phenolformaldehydharpiks					0,0E+00	kg	0,0E+00	kg									
	0,01	kg	Additives					0,0E+00	kg	0,0E+00	kg									
0,90	**kg**	**Plate developer**						**40%**		**60%**										
	0,90	kg	Water					0,32579	kg	4,9E-01	kg									
	0,08	kg	Na2SiO3					0,02896	kg	4,3E-02	kg									
	0,02	kg	NaOH					0,00724	kg	1,1E-02	kg									
0,0300	**kg**	**Gumming agent**						**100%**												
	0,85	kg	Water					0,02552	kg											
	0,05	kg	CMC					0,00150	kg			WW redist			New values					
	0,05	kg	Citric acid					0,00150	kg			soil	air	wat	soil	air	water			
	0,05	kg	Na-dodecyl-diphenyloxid-disulphonate					0,00150	kg			33%	0%	2%	0,0005	0	3E-05			
	0,00133	kg	Biocide																	
		0,25	kg	2-methyl-3-isothiazolon				0,000010	kg			0%	0%	59%	0	0	5,9E-06			
		0,75	kg	5-chlor-2-methyl-3-isothiazolon				0,000030	kg			0%	0%	59%	0	0	1,8E-05			
0,00125	**kg**	**Biocide**						**100%**												
	0,25	kg	2-methyl-3-isothiazolon					0,00031	kg			0%	0%	59%	0	0	0,00018			
	0,75	kg	5-chlor-2-methyl-3-isothiazolon					0,00093	kg			0%	0%	59%	0	0	0,00055			
								10%												
0,187	**kg**	**Alternativ biocid (benzalkoniumchloride)**						0,01871	kg	168g(soil)										
37,42	**kg**	**Water for rinsing**																		
3,44	**kg**	**Remelting of aluminium**																		
3,44	**kg**	**Avoided production of primary aluminium**																		

					Emissions and waste handling											
1 ton generic sheet fed offset printed matter (fu)					**-to air**		**-to ww**		**-chem.waste**		**-recycling**		**vol.waste**		**-incineration**	
Piece	**Printing (per fu)**				Chemical waste sum				1,14	kg						
3,93	**kg**	**IPA**			3,392	kg	0,536	kg								
5,80	**kg**	**Printing Ink**					**1%**		**19,6%**		WW redist			New values		
	0,085	kg	CI pigment yellow 14								soil	air	wat	soil	air	water
	0,075	kg	CI pigment blue 15		5%		0,0029	kg	0,0567	kg	95%	0%	5%	0,00276		0,00015
			CI pigment red 57:1		5%		0,0029	kg	0,0567	kg	4%	0%	96%	0,00012		0,00278
			CI pigment yellow 12		6%		0,0035	kg	0,0681	kg	95%	0%	5%	0,00331		0,00017
	0,030	kg	Carbon black		3%		0,0017	kg	0,0340	kg						
	0,200	kg	Modif.phenolharpikser				0,012	kg	0,23	kg						
	0,120	kg	Soyaoliealkyder				0,00696	kg	0,14	kg						
	0,120	kg	Soya oil				0,00696	kg	0,14	kg						
	0,290	kg	n-parrafin (heavy)				0,017	kg	0,33	kg	85%	6%	6%	0,0143	0,00101	0,00101
	0,030	kg	wax				0,00174	kg	0,03	kg						
	0,050	kg	Additives, incl sikkatives				0,0029	kg	0,06	kg						
1,004	**kg**	**Fountain solution concentrate**			**86%(IPA)**		**100%(+IPA)**									
	0,03	kg	IPA		0,026	kg	0,0041	kg	*0,004*	kg				WW redistr.		
	0,03	kg	Diethylene glycol		0,000	kg	0,030	kg						Water		
	0,0025	kg	2-brom-2-nitropropane-1,3-diol (biocide)				0,002511	kg						1,48g		
	0,0006	kg	Biocide													
		0,25	kg	2-methyl-3-isothiazolon			0,0001507	kg						0,085g		
		0,75	kg	5-chlor-2-methyl-3-isothiazolon			0,000452	kg						0,267g		
	0,9369	kg	Water													
28,83	**kg**	**Water for dilution**														
Piece	**Finishing (per fu)**				Chemical waste sum				0,04	kg						
4,98	**kg**	**Water based lacquer**					**5%**									
	0,25	kg	Acrylates (poly-, mono-, esters)				0,0622									
	0,03	kg	Glycerol				0,0075									
	0,02	kg	Ethanol				0,0050									
	0,01	kg	Ammonia				0,0025									
	0,01	kg	Polyethylene wax				0,0025				WW redist			New values		
	0,01	kg	2-amino-ethanol				0,0025				soil	air	wat	soil	air	water
	0,01	kg	Alcoholethoxylate (undecyletherpolyoxy-ethylen(5))				0,0025				85%	6%	6%	0,00212	0,00015	0,00015
	0,0004	kg	2-chloroacetamide (biocide)				0,0001									
	0,6596	kg	Water													
0,22	**kg**	**"Offset lacquer"**					**0,1%**		**19,6%**							
	0,24	kg	Modif.phenolharpikser				0,00005	kg	0,010	kg						
	0,14	kg	Soyaoliealkyder				0,00003	kg	0,006	kg	WW redist			New values		
	0,14	kg	Soyaolie				0,00003	kg	0,006	kg	soil	air	wat	soil	air	water
	0,40	kg	n-paraffin (heavy)				0,0001	kg	0,017	kg	0%	0%	59%	0	0	5,2E-05
	0,03	kg	polyethylene wax				0,00001	kg	0,001	kg						
	0,05	kg	Additives, incl siccatives				0,00001	kg	0,002	kg						
0,75	**kg**	**Hotmelt glue**														
	0,38	kg	EVA	LDPE used												
	0,48	kg	Resin	Phenolic formaldehyde resin												
	0,14	kg	Wax								WW redist			New values		
	0,0015	kg	Antioxidant								soil	air	wat	soil	air	water
Piece	**Cleaning (per fu)**				Chemical waste sum				0,87	**kg**						
0,61	kg	Soyaolie (veg.)					0,0061	kg	0,61	kg						
0,61	kg	n-parafines (heavy)			0,42	kg	0,0061	kg	0,19	kg	85%	6%	6%	0,0052	0,41784	0,00037
0,61	kg	"Ekstraktionsbenzin"														
	0,999	kg	n-parafines (light)		0,58	kg	0,00061	kg	0,030	kg	15%	44%	12%	9,2E-05	0,58046	7,3E-05
	0,001	kg	Benzene (aromatic)		0,00058	kg	6,11E-07	kg	0,000030	kg						
0,61	kg	Ethanol (alcohol based)			0,58	kg	0,0061	kg	0,024	kg						
0,050	kg	Alcoholethoxylate (undecyletherpolyoxy-ethylen(5))				kg	0,025	kg	0,025	kg	29%	0%	2%	0,00724	0	0,0005
21,98	kg	Water for rinsing														
Piece	**Energy consumption at printing company (per fu)**															
176,103	kWh	District heating														
21,606	kg	Heating with fuel oil														
6,25	kg	Heating with natural gas														
705,324	kWh	Electricity consumption														
Piece	**Disposal after use**															
634,243	kg	Paper to recycling														
634,243	kg	Avoided production of paper														
562,4	kg	Incineration of paper														
Piece	**Paper for 1 ton offset product**															
1196,7	**kg**	**Paper**									**196**	**kg (paper recycling at model printing company)**				
Piece	**Water consumption excl. process water**															
1070,17	**litres**	**Water**														

6.6 Data on eleven real world offset printing companies

Inventory data on consumption and emissions from the printing companies that have contributed to this study is shown in the tables below. The data are based on:One sheet fed, one heatset and one cold-set-newspaper (Larsen et al. 1995), six sheet fed (Anonymous 1-6: Danish printing companies' data from 1999, 2000 and 2002) and two cold-set-newspaper (Axelsson et al. 1997). Only the data referred to in Section 2 of this report (Tables 12 and more) are actually used. Data from the Swedish technical background document (Brodin and Korostenski 1995) also used in this study are not shown.

Printing industry	Unit	Sheet fed	Heatset	Coldset	Sheet fed	Sheet fed	Sheet fed	Coldset	Coldset	Sheet fed	Sheet fed	Sheet fed		Average
Production, t	t prod.	2109,2	7803,2	28780	297,8	211	442	12,60	3,94	2108				

Repro consumption

Total														
Film	m2				*157stk*	1493	4316	24	14,9					
Film developer	l				1080	560	1390	1,2	1	1800				
Fixer	l				2800	580	1820	0,3	3,74	1400				
Water	l						1500	3						
Per produced amount														
Film/t prod	m2/t prod					7,08	9,76	1,90	3,78					**5,63**
Film developer/t prod	l/t prod				3,63	2,65	3,14	0,10	0,25	0,85				**1,77**
Fixer/t prod	l/t prod				9,40	2,75	4,12		0,95	0,66				**3,58**
Rinsing water	l/t prod			11,6			5,50	0,24						**5,77**

Repro emissions

Film														
-to recycling	m2				*193kg*			24	14,9					
-to recycling	%							100%	100%					100,0%
-to recycling/t prod	m2/t prod													**5,63**
Film developer														
-to recycling	kg							1,2	1					
-to recycling	%							100%	100%					100,0%
-to recycling/t prod	l/t prod							0,10	0,25					**1,77**
-to wastewater	kg													
-to wastewater	%													
-to wastewater/t prod	l/t prod													**0,00**
-as chemical waste	kg													
-as chemical waste	%													0,0%
-as chemical waste/t prod	l/t prod													**0,00**
Fixer														
-to recycling	kg				2450									
-to recycling	%				87,5%									87,5%
-to recycling/t prod	kg/ton prod				8,2									**3,13**
-to wastewater	kg													
-to wastewater	%													
-to wastewater/t prod	l/t prod													**0,00**
-as chemical waste	kg													
-as chemical waste	%													12,5%
-as chemical waste/t prod	l/t prod													**0,45**

Platemaking consumption

Total														
Plate	m2		7800	54000,0	*13100stk*	1784	*12310 stk*	29,0	15,1					
Plate developer	l		1100		945	200		3,5	1,75	5900				
Plate developer	kg		1196,8	2700	1028,16	217,6		3,808	1,904	6419,2				
Gumming agent	t		0,26	0,15						0,115				
Per produced amount														
Plate/t prod	m2/t prod		1,00	1,88		8,45		2,30	3,82		7,50			**4,16**
Plate developer/t prod	kg/t prod		0,15	0,094	3,45	1,03		0,30	0,48	3,05				**1,22**
Gumming agent	kg/t prod		0,0333	0,0052						0,0546	0,027			**0,030**
Water	kg/t prod		16,7	54,0	33	46								**37,42**

Platemaking emissions

Plate														
-to recycling	%	100%	100%	100%	100%									100%
	m2/t prod													**4,16**
Plate developer														
-to wastewater	t		0,16	1,1										
-to wastewater	%		14,50%											15%
-to wastewater/t prod	kg/ton prod													**0,177**
-as chemical waste	t		0,9	1,6										
-as chemical waste	%		81,70%											82%
-as chemical waste/t prod	kg/ton prod													**0,999**
-to recycling	t													
-to recycling	%		0%	0%										0%
-to recycling/t prod	kg/ton prod													**0,000**

Printing

Paper, consumption														
Paper input	t	2200	8500	30500	438	283	598	13	4	2964				
Paper input/ton production	kg/t prod	1043,1	1089,3	1059,8	1472,0	1341,2	1352,9	1034,0	1124,2	1406,1	1194,0			**1211,7**
Paper, emission														
Paper to recycling	t	100	800	2100	140,5	72	157,6	0,429	0,489	856				
Waste percentage (recyc.)	% w/w	4,5%	9,4%	6,9%	32,1%	25,4%	26,4%	3,3%	11,0%	28,9%				16,4%
Waste/ton prod	kg waste/t prod													**199,1**
IPA, consumption														
IPA consumption, t	t	8,8	26		1,24	2,19	1,26							
kg IPA/t prod.	kg IPA/t prod.	4,17	3,33		4,18	10,38	2,84					4,22		**4,85**
IPA, emission														
-to air	t	7,60												
-to air	%	86,4%												86,4%
-to air/t prod	kg /t prod													**4,2**
-to ww	t	1,20												
-to ww	%	13,6%												13,6%
-to ww/t prod	kg /t prod													**0,7**

Printing industry	Unit	Sheet fed	Heatset	Coldset	Sheet fed	Sheet fed	Sheet fed	Coldset	Coldset	Sheet fed	Sheet fed	Sheet fed		Average
Production, t	t prod.	2109,2	7803,2	28780	297,8	211	442	12,60	3,94	2108				
Printing ink, consumption														
Ink input	t	9,5	150	380	2,172	2,8	2,979	0,201	0,1043	13,976				
Ink consumption/t prod	kg ink/t prod	4,5	19,2	13,2	7,3	13,3	6,7	15,9	26,5	6,6	12,0	7,6		**12,1**
Ink, emission														
Ink waste to chem waste	t	0,5	9	9	1,002	0,485	1,367							
Waste percentage	% w/w	5,3%	6,0%	2,4%	46,1%	17,3%	45,9%				14,0%			19,6%
-to chemical waste/t prod	kg/t prod													**2,36**
Fountain solution conc. consumption														
Fountain solution conc.	t	1	4,5	22	0,275	0,4		0,012		2,885				
kg consumption per t. prod.	kg konc/t prod.	0,474	0,577	0,764	0,924	1,896		0,952		1,369	1,08			**1,004**
Fugtevandkonc., emission														
-to air	t	0,4		13										
-to air	%	40%												40,0%
-to air/t prod	kg/t prod													**0,402**
-to ww	t	0,5		0										
-to ww	%	50%												50,0%
-to ww/t prod	kg/t prod													**0,502**
Water for dilution														
Input, kg/t prod	kg/t prod	11,379		46,282										**28,831**

Cleaning agents, consumption

		ton	ton	ton	litres	litres	litres	litres	litres	ton				
Veg.oil	-	0,76	0,4	6,9		240								
Organic solvent	-	3,2	6,1	16		590								
Detergents	-	0,1												
Total washing	ton	4,06	6,5	22,9	1062	830	5800	4,6	3	1,902				
Water for rinsing	kg	1,4	2	20										
		kg/ton prod		kg/ton prod	*l/ton prod.*	kg/ton prod.		*l/ton prod.*						
Veg. oil/t prod	kg/t prod	0,36	0,051	0,24		1,13						2,56		**0,87**
Org. solv./ton prod.	kg/t prod	1,52	0,78	0,56		2,33						0,32		**1,10**
Deter/ton prod	kg/t prod	0,05												**0,05**
Total wash/t prod.	kg/t prod	1,92	0,83	0,80	*2,89*	*3,19*	*10,63*	*0,30*	*0,62*	0,90		*2,88*		**2,50**
Water for rinsing	kg/t prod	65,00	0,26	0,69										**21,98**
		4,06												

Cleaning agents, emission

Veg.oil		ton		ton	litres	litres		litres	litres					
-to chem waste	t	0,76		6,90										
-to chem waste	%	100%		100%										100%
-to chem waste/t prod														**0,87**
Organic solvent														
-to air	t	1,80	4,90											
-to air	%	56%	80%											68%
-to air/t prod	kg/t prod													**0,75**
-to ww	t	0,20	0,00											
-to ww	%	6%	0%											3%
-to ww/t prod	kg/t prod													**0,03**
-to chemical waste	t	1,20	1,20	16,00										
-to chemical waste	%	38%	20%											29%
-to chemical waste/t prod	kg/t prod													**0,31**

Finishing, consumption

Water based lacquer	t				0,151	1,58				14,69				
Water based lacquer/t prod	kg/t prod				0,51	7,46				6,97				**4,98**
Oil based lacquer	t				0,084	0,080				0,012				
Oil based lacquer/t prod	kg/t prod				0,28	0,38				0,006				**0,22**
Hotmelt glue	t				0,020					3,03				
Hotmelt/t prod	kg/t prod				0,067					1,435				**0,75**

Energy consumption

				Density of gas oil		0,84		kg/l						
Total				Density of nat. gas		0,81		kg/m3						
District heating	kWh							9640						
Heating with fuel oil	l				15313	8471	5000							
Heating with natural gas	m3				8313		1300							
Electricity consumption	kWh				248005	152811	278046	8510	645					
Per produced amount														
District heating/t prod	kWh/t prod				0,0	0,0	0,0	764,8				115,7		**176,1**
Heating with fuel oil/t prod	kg/t prod				43,2	33,7	9,5	0,0						**21,6**
Heating with fuel oil/t prod	kWh/t prod				486,0	379,4	106,9	0,0						**243,1**
Heating with natural gas/t pro	kg/t prod				22,6	0,0	2,4	0,0						**6,2**
Heating with natural gas/t pro	kWh/t prod				303,7	0,0	32,0	0,0						**83,9**
Elec. con./t prod.	kWh/t prod				832,9	724,2	629,1	675,2			858,0	512,6		**705,3**
					1622,6	**1103,6**	**768,0**	**1440,0**						**1208,4**

Water consumption

Water consumption	m3	2400		11100	800	248	170							
Water consumption/t prod.	kg/t prod	1137,90		385,68	2686,68	1175,36	384,62				1599	780		**1164,18**
Moisturiser conc. dilution	%	1%		12%										
Sanitary	%	20%		24%			99%							
Film developing	%	10%		3%			0,18%							
Washing	%	9%												
Air moisture	%	60%		47%										
Platemaking	%			14%			0,71%							
Moisturiser conc. dilution	kg/t prod	11,4		46,3										
Sanitary	kg/t prod	227,6		92,6										
Film developing	kg/t prod	113,8		11,6										
Cleaning	kg/t prod	102,4												
Air moisture	kg/t prod	682,7		181,3										
Platemaking	kg/t prod			54,0										

Inventory data for the reference scenario

A full compilation of all emissions and resource consumptions included in the reference scenario is shown below. The impact categories covering ecotoxicity and human toxicity are marked with a ”0” if a characterisation factor is not included and ”1” if a characterisation factor is included.

IPU-MSH/HFL-C00200M Offset product, 1 ton, marginal energy

EDIP level Inventory

Type	ID-nr.	Name	Amount	Unit
Waste	B32666	Unspecified reuse	6,56E-04	kg
Waste	IPU-CE-T0001	Unspecified metal	2,84E-05	kg
Waste	IPU-NF-T1408	Radioactive waste, low	4,07E+01	g
Waste	IPU-NF-T2088	Catalyst mat.	5,72E-03	kg
Waste	K32348	Unspecified lubricator	6,12E-09	kg
Waste	K32375	Unspecified auxilaries	1,18E-11	kg
Waste	M32371	Cardboard, fluting/liner (reuse 100%)	2,66E-12	kg
Waste	M32422	Plast, PVC	4,95E-09	kg
Waste	M32464	zz-Al i malm (bauxit)	3,64E-11	kg
Waste	M32466	zz-Cu i malm	8,58E-11	kg
Waste	M32622	zz-Zinkkoncentrat	9,52E-09	kg
Waste	R32477	Quartz	8,72E-01	g
Waste	R32631	Wood (hard) dry matter, raw material	2,03E-12	g
Waste	S32471	Dolomite	2,29E-05	g
Waste	S32598	Natriumhydroxid (NaOH)	2,38E-06	g
Waste	S32613	Tot-P	2,42E+00	g
Waste	S32618	Tot-N	2,42E+01	g
Waste	S32633	Sand (SiO2)	8,54E-06	g
Waste	S32656	Zn (zink)	1,29E+00	g
Waste	S32675	Pb (bly)	1,53E-01	g
Waste	S32693	Ni (nikkel)	1,37E-01	g
Waste	S32707	Hg (Kviksølv)	4,03E-04	g
Waste	S32718	Cu (kobber)	3,55E+00	g
Waste	S32737	Cd (cadmium)	2,34E-03	g
Waste	S32760	Cr (chrom)	3,30E-01	g
Waste	T32157	Unpec. Biomass	4,04E+00	kg
Waste	T32168	Wood	1,04E-05	kg
Waste	T32259	Unpec. plastic wasteaffald "pure"	1,85E-03	kg
Waste	T32301	Sand	2,98E-02	kg
Waste	T32346	Steel shavings	3,84E-07	kg
Waste	T32347	Iron shavings	3,68E-07	kg
Waste	T32353	Cardboard	2,54E-05	kg
Waste	T32354	Paper	5,99E-05	kg
Waste	T32361	Mn containing slag	2,55E-03	kg
Waste	T32367	Glas waste, heavy metal containing	3,59E-06	kg
Waste	T32368	Glas waste	3,84E-04	kg
Waste	T32383	Zn containing dust	3,82E-03	kg
Waste	T32384	Iron containing slag	1,01E-01	kg
Waste	T32385	Heavy metal containing soil and sand	1,36E-03	kg
Waste	T32388	Unpec. dust containing heavy metals	5,30E-03	kg
Waste	T32389	Unspec. heavy metal containing sludge	6,24E-04	kg
Waste	T32390	Unspec. slag and ashes	1,75E-01	kg
Waste	T32391	Unspec. scrap waste	3,06E-01	kg
Waste	T32392	Unspec. oil waste	1,56E+00	kg
Waste	T32393	Unspec. bauxit waste	3,91E-01	kg
Waste	T32394	Unspec. industry waste	8,66E+00	kg
Waste	T32395	Unspec. waste from steel production 2	2,47E-03	kg
Waste	T32396	Unspec. waste from steel production 1	2,85E-02	kg
Waste	T32397	Cr containing slag	4,11E-02	kg
Waste	T32398	Unspec. slag and ashes, incineration	6,15E+00	kg
Waste	T32399	Unspec. chemical waste	2,29E+00	kg
Waste	T32400	Mineral based waste	2,25E-01	kg
Waste	T32401	Unspec. waste	5,38E-01	kg
Waste	T32404	HCL in slag and ashes	2,49E-05	kg
Waste	T32405	Unspec. sludge	2,58E+01	kg
Waste	T32407	Unspec. slag and ashes, energy	9,44E-01	kg
Waste	T32408	Unspec. nuclear waste	1,99E+00	g
Waste	T32409	Unspec. bulk waste	8,04E+00	kg
Waste	T32412	Unspec. dust, non-hazardous	6,08E-10	kg
Waste	T32413	Unspec. Slag	1,20E-02	kg
Waste	T32415	Uspec. hazardous waste	1,13E-01	kg
Waste	T32521	Uspec. Rubber	6,17E-03	kg
Waste	T32675	Pb	9,76E-09	kg
Auxilaries	IPU-NF-M1473	CaCO3	2,55E-02	kg
Auxilaries	K32585	Calciumfluorid (CaF2)	8,24E-03	kg
Auxilaries	R32649	Unspec. water	2,75E+01	g
Auxilaries	R32652	Natriumchlorid (NaCl)	4,71E+01	g

Type	ID-nr.	Name	Amount	Unit	Hum.tox	Ecotox
Air emission	COWI-ALS-42418-190	Unspec. dust	9,14E+03	g	0	0
Air emission	IPU-MSH/HFL-S00227	Ethanol	3,50E+02	g	1	1
Air emission	IPU-MSH/HFL-S00234	Hexane	3,50E+02	g	1	1
Air emission	IPU-NC-S101	Benz(a)pyren	5,24E-05	g	0	0
Air emission	IPU-NC-S102	Radioactive emission	1,15E+04	kBq	0	0
Air emission	IPU-NC-S122	Co	-3,04E-04	g	0	0
Air emission	IPU-NC-S125	NMVOC, base load elec.	8,46E-02	g	0	0
Air emission	IPU-NF-S2680	VOC, diesel engine	7,00E-01	g	0	0
Air emission	IPU-NF-S2729	Particles TSP, diesel engine	1,21E-01	g	0	0
Air emission	S32135	HFC-134a	3,85E-08	g	0	0
Air emission	S32152	Acetic acid	1,57E-02	g	1	1
Air emission	S32175	Cyanid (CN-)	1,39E-04	g	0	0
Air emission	S32418	Dioxine	3,94E-06	g	1	1
Air emission	S32420	Unspec. Cl containing organic substances	2,48E-04	g	0	0
Air emission	S32421	Chlor (Cl2)	7,71E-03	g	1	0
Air emission	S32423	Naphtalen	2,02E-09	g	0	0
Air emission	S32424	1,1,1-trichloropropan	2,62E-09	g	0	0
Air emission	S32425	Propylen oxid	4,28E-08	g	1	1
Air emission	S32426	Dichloropropane	2,09E-07	g	0	0
Air emission	S32427	Epichlorohydrin	3,86E-08	g	0	0
Air emission	S32429	Nitrobenzen	1,31E-08	g	0	0
Air emission	S32432	Toluen	5,72E-08	g	1	1
Air emission	S32472	Mn(mangan)	8,53E-02	g	1	1
Air emission	S32525	NMVOC, aeroplane engine	1,95E-08	g	0	0
Air emission	S32608	Sr (strontium)	4,22E-04	g	0	1
Air emission	S32609	Sulfat (SO4--)	8,71E+00	g	0	0
Air emission	S32610	Unspec. Oxides	2,70E-02	g	0	0
Air emission	S32613	Tot-P	2,72E-04	g	0	0
Air emission	S32615	Unspec. Oil	7,82E-06	g	0	0
Air emission	S32627	B (bor)	4,08E-02	g	0	0
Air emission	S32633	Sand (SiO2)	6,10E-04	g	0	0
Air emission	S32637	NH4-N	1,35E-03	g	0	0
Air emission	S32638	Mg (magnesium)	1,21E-02	g	0	0
Air emission	S32642	Fluorid (F-)	3,90E-01	g	1	0
Air emission	S32656	Zn (zink)	3,04E-02	g	1	1
Air emission	S32658	Water	2,37E-02	g		
Air emission	S32659	V (vanadium)	1,15E+00	g	1	1
Air emission	S32660	U (uran)	6,41E-06	g	0	0
Air emission	S32662	1,1,1-trichlorethan	8,87E-05	g	1	0
Air emission	S32664	TOC	1,92E-03	g	0	0
Air emission	S32665	Tl (thallium)	1,15E-06	g	1	1
Air emission	S32666	Th (thorium)	6,67E-06	g	0	1
Air emission	S32668	Styren	2,12E-04	g	1	1
Air emission	S32669	Sn (tin)	9,34E-06	g	0	0
Air emission	S32670	Se (selen)	1,45E-03	g	1	1
Air emission	S32671	Sb (antimon)	5,18E-05	g	1	0
Air emission	S32673	Phenol	2,12E-06	g	1	1
Air emission	S32674	VOC, oliefyring	6,71E+00	g	0	0
Air emission	S32675	Pb (bly)	2,58E-02	g	1	1
Air emission	S32676	VOC, natural gas heating	1,95E+01	g	0	0
Air emission	S32678	VOC, coal heating	6,67E-02	g	0	0
Air emission	S32680	VOC, diesel engine	2,00E+00	g	0	0
Air emission	S32681	VOC	5,60E+01	g	0	0
Air emission	S32684	NMVOC, waste incineration	6,22E+01	g	0	0
Air emission	S32685	NMVOC, power station	6,69E-01	g	0	0
Air emission	S32687	NMVOC, natural gas heating	8,16E+00	g	0	0
Air emission	S32688	NMVOC, oil heating	1,74E+00	g	0	0
Air emission	S32689	NMVOC, diesel engine	4,03E+01	g	0	0
Air emission	S32690	NMVOC, painting processes	4,06E-07	g	0	0
Air emission	S32691	NMVOC, gasoline engine without cat.	1,77E-01	g	0	0
Air emission	S32692	Unspec. iron oxides	2,01E-02	g	0	0
Air emission	S32693	Ni (nikkel)	3,69E-01	g	1	1
Air emission	S32694	Ammoniak (NH3)	9,13E-02	g	0	0
Air emission	S32695	Dinitrogenoxid (N2O)	1,61E+01	g	1	0
Air emission	S32696	Nitrogen (N2)	8,60E+00	g	0	0
Air emission	S32699	Mo (molybdæn)	-1,15E-04	g	0	0
Air emission	S32706	2-propanol (isopropanol)	3,42E+03	g	1	1
Air emission	S32707	Hg (Kviksølv)	2,04E-03	g	1	1
Air emission	S32708	Hydrogenfluorid (HF)	2,67E-01	g	0	0
Air emission	S32711	Hydrogencarboner (HC)	2,51E+02	g	0	0
Air emission	S32712	Hydrogen (H2)	3,85E-01	g	0	0
Air emission	S32713	Formaldehyde	8,99E-05	g	1	1
Air emission	S32714	NMVOC	6,50E+02	g	0	0
Air emission	S32715	Unspec. Fluorides	4,32E-05	g	0	0
Air emission	S32716	Fe (jern)	-4,18E-03	g	1	1
Air emission	S32718	Cu (kobber)	1,15E-02	g	1	1
Air emission	S32722	Chrom(III)	2,39E-04	g	0	0
Air emission	S32723	Carbonmonooxid (CO)	8,13E+02	g	1	0
Air emission	S32725	Methan (CH4)	4,75E+02	g	0	0
Air emission	S32729	Unspec. particles	7,56E+01	g	0	0
Air emission	S32731	Uspec. metals	2,08E-01	g	0	0
Air emission	S32733	Unspec. C9-C10 aromates	1,80E-01	g	0	0
Air emission	S32734	Unspec. org. compounds	2,43E-01	g	0	0
Air emission	S32735	Unspec. Matter	6,61E-09	g	0	0
Air emission	S32737	Cd (cadmium)	8,87E-04	g	1	1
Air emission	S32738	Ca (calcium)	2,77E-03	g	0	0
Air emission	S32741	Benzene	3,57E-01	g	1	1
Air emission	S32742	As (arsen)	3,51E-03	g	1	1
Air emission	S32744	Unspec. aldehyde	3,18E-02	g	0	0
Air emission	S32754	Unspec. heavy metals	3,35E-02	g	0	0
Air emission	S32755	Svovldioxid (SO2)	1,99E+03	g	1	0
Air emission	S32756	Nitrogenoxider (NOx)	2,86E+03	g	1	0
Air emission	S32757	Hydrogenchlorid (HCl)	1,71E+00	g	0	0
Air emission	S32758	Hydrogensulfid (H2S)	7,48E-02	g	1	0
Air emission	S32759	PAH	5,55E-02	g	0	0
Air emission	S32760	Cr (chrom)	1,07E-03	g	0	0
Air emission	S32761	Carbondioxid (CO2)	1,33E+06	g		
Air emission	S32764	Chlorid (Cl-)	1,74E-01	g	0	0
Air emission	T32412	Unspec. dust, non-hazardous	6,20E-12	kg	0	0
Air emission	TX-S-220	Tetradecan (mineral oil)	2,50E+02	g	1	1

Type	ID-nr.	Name	Amount	Unit
Resource	COWI-ALS-42418-167	Kaliumchlorid (KCl)	9,12E-01	g
Resource	HE-M3009	Ag (primær)	-5,61E-02	kg
Resource	HE-R3002	Ag (sølv)	5,63E+01	g
Resource	IPU-CE-R0002	Fluorspar	1,83E-03	g
Resource	IPU-MSH/HFL-R00238	Kaolin	3,58E+05	g
Resource	IPU-NF-R1045	Cooling water	1,30E+08	g
Resource	IPU-NF-R2089	Atmosfærisk luft	3,35E+03	g
Resource	IPU-NF-R2410	S (svovl)	1,29E-01	g
Resource	IPU-NF-R2650	Barit	3,56E+02	g
Resource	IPU-NF-R2654	Ler, bentonit	2,34E+01	g
Resource	IPU-NF-R2660	Kaliumchlorid (KCl)	6,94E-03	g
Resource	R32063	Anthracite	1,85E+03	g
Resource	R32148	Unspec. Minerals	2,71E+02	g
Resource	R32162	Unspec. biomass, dry matter, raw material	9,98E+00	g
Resource	R32184	Bakkematerialer	3,88E-04	g
Resource	R32208	Straw dry matter, fuel	6,35E-05	g
Resource	R32209	Wood (soft) dry matter, fuel	5,69E+05	g
Resource	R32210	Wood (soft) dry matter, raw material	3,71E+05	g
Resource	R32211	Anthracite, raw material	1,07E+02	g
Resource	R32212	Oil, raw material	8,24E+03	g
Resource	R32213	Natural gas, raw material	3,77E+03	g
Resource	R32253	Soil	-8,03E+03	g
Resource	R32326	Unspec. resources	1,96E+01	g
Resource	R32477	Quartz	1,96E+02	g
Resource	R32479	Mn (mangan)	3,74E+00	g
Resource	R32487	Cr (Chrom)	2,03E+01	g
Resource	R32498	Hydrogen, fuel	3,69E+00	g
Resource	R32612	Unspec. fuel	-1,34E+03	MJ
Resource	R32628	U (Uran)	1,40E+00	g
Resource	R32630	Unspec. biomass, dry matter, fuel	4,15E+02	g
Resource	R32631	Wood (hard) dry matter, raw material	1,83E-01	g
Resource	R32646	Dam water	1,30E+07	g
Resource	R32647	Surface water	3,01E+04	g
Resource	R32648	Ground water	1,47E+06	g
Resource	R32649	Unspec. water	4,60E+07	g
Resource	R32650	Ni (nikkel)	8,68E+00	g
Resource	R32651	Zn (zink)	1,51E-01	g
Resource	R32652	Natriumchlorid (NaCl)	1,56E+04	g
Resource	R32653	Clay	2,95E+05	g
Resource	R32654	Cu (kobber)	9,42E+00	g
Resource	R32655	Calciumcarbonat (CaCO3)	6,46E+04	g
Resource	R32749	Natural gas, fuel	3,02E+05	g
Resource	R32750	Lignite, fuel	4,39E+03	g
Resource	R32751	Anthracite, fuel	8,72E+03	g
Resource	R32753	Fe(jern)	2,16E+02	g
Resource	R32762	Al (aluminium)	3,17E+02	g
Resource	R32763	Oil, fuel	1,16E+05	g
Resource	S32221	Natriumcarbonat (NaCO3)	2,47E-06	g
Resource	S32266	Propylenglycol monoeth.ether	4,41E-07	g
Resource	S32548	Epoxy	1,75E-10	g
Resource	S32633	Sand (SiO2)	1,91E-03	g
Resource	S32659	V (vanadium)	1,55E-11	g
Resource	S32694	Ammoniak (NH3)	3,39E-06	g
Resource	S32699	Mo (molybdæn)	1,20E-10	g
Resource	S32738	Ca (calcium)	6,15E-03	g
Resource	S32742	As (arsen)	2,58E-13	g
Resource	S32757	Hydrogenchlorid (HCl)	8,47E-07	g
Resource	S32760	Cr (chrom)	1,89E-10	g
Resource	T32347	Iron shavings	1,25E-12	kg

Type	ID-nr.	Name	Amount	Unit	Hum.tox	Ecotox
Water emission	IPU-MSH/HFL-S00222	Unit impact. 1m3 water etwa (pigment production)	4,79E+03	m3	0	1
Water emission	IPU-MSH/HFL-S00223	Unit impact. 1m3 water etwc (pigment production)	9,08E+03	m3	0	1
Water emission	IPU-MSH/HFL-S00224	Unit impact. 1m3 soil etsc (pigment production)	1,92E+03	m3	0	1
Water emission	IPU-MSH/HFL-S00227	Ethanol	8,70E+00	g	1	1
Water emission	IPU-MSH/HFL-S00234	Hexane	3,70E-01	g	1	1
Water emission	IPU-MSH/HFL-S00235	Ag (sølv)	2,40E-04	g	1	1
Water emission	IPU-MSH/HFL-S00237	CI pigment blue 15	2,90E+00	g	0	1
Water emission	IPU-MSH/HFL-S00242	CI pigment red 57:1	2,90E+00	g	0	1
Water emission	IPU-MSH/HFL-S00245	Glycerol	7,50E+00	g	1	1
Water emission	IPU-MSH/HFL-S00246	CI pigment yellow 12	3,50E+00	g	1	1
Water emission	IPU-MSH/HFL-S00247	2-methyl-3-isothiazolon	5,20E-01	g	0	1
Water emission	IPU-MSH/HFL-S00248	5-chlor-2-methyl-3-isothiazolon	1,55E+00	g	0	1
Water emission	IPU-MSH/HFL-S00250	Hydroquinone	2,10E+00	g	0	1
Water emission	IPU-MSH/HFL-S00251	2-amino-ethanol	2,50E+00	g	0	1
Water emission	IPU-MSH/HFL-S00263	Na-dodecyl-diphenyloxid-disulphonate	1,50E+00	g	0	1
Water emission	IPU-MSH/HFL-S00264	2-brom-2-nitropropane-1,3-diol (biocide)	2,50E+00	g	0	1
Water emission	IPU-MSH/HFL-S00266	Undecyletherpolyoxy-ethylen(5)	1,75E+01	g	0	1
Water emission	IPU-MSH/HFL-S00267	2-chloroacetamide (biocide)	1,00E-01	g	0	1
Water emission	IPU-NC-S102	Radioactive emission	5,40E+01	kBq	0	0
Water emission	IPU-NF-S1738	Ca++ (Calciumion)	1,54E-03	g	0	0
Water emission	IPU-NF-S1745	Al+++ (aluminiumion)	1,06E-03	g	0	0
Water emission	IPU-NF-S2160	K+ (kaliumion)	2,71E-02	g	0	0
Water emission	IPU-NF-S2170	Carbonat (CO3--)	2,46E-02	g	0	0
Water emission	K32136	Oil products, refined (auxiliaries)	1,21E-12	kg	0	0
Water emission	K32332	Zn (zink)	2,57E-13	kg	1	1
Water emission	K32348	Unspec. Lubricators	9,01E-12	kg	0	0
Water emission	K32417	Unspec. water	1,45E-09	kg		
Water emission	K32567	Nitrogen (N2)*	1,75E-11	kg	0	0
Water emission	K32577	Phosphoric acid	2,87E-11	kg	0	0
Water emission	R32649	Unspec. water	4,15E-06	g		
Water emission	R32650	Ni (nikkel)	1,54E-11	g	1	1
Water emission	S32152	Acetic acid	2,00E+01	g	1	1
Water emission	S32170	Unspec. detergent	3,42E-03	g	0	0
Water emission	S32175	Cyanid (CN-)	1,73E-02	g	0	0
Water emission	S32230	Chlorat (ClO3-)	1,19E-02	g	0	0
Water emission	S32327	Silikat-ion (SiO3)	2,28E-05	g	0	0
Water emission	S32358	Diethylenglycol	3,24E+01	g	1	1
Water emission	S32420	Unspec. Cl comtaining organic compounds	4,18E-06	g	0	0
Water emission	S32432	Toluen	5,66E-05	g	1	1
Water emission	S32472	Mn(mangan)	2,50E-01	g	1	1
Water emission	S32540	Unspec. metal removing fluid	1,97E-04	g	0	0
Water emission	S32549	Unspec. nonionic-detergent	1,09E-07	g	0	0
Water emission	S32550	Unspec. anionic-detergent	3,44E-06	g	0	1
Water emission	S32598	Natriumhydroxid (NaOH)	7,24E+00	g	0	0
Water emission	S32608	Sr (strontium)	2,69E+01	g	0	1
Water emission	S32609	Sulfat (SO4--)	2,22E+02	g		
Water emission	S32610	Uspec. Oxids	1,23E-01	g	0	0
Water emission	S32611	Si (silicium)	4,80E-09	g	0	0
Water emission	S32613	Tot-P	2,55E+01	g		
Water emission	S32614	Unspec. disolved matter	1,41E+01	g	0	0
Water emission	S32615	Unspec. oil	7,17E+01	g	0	0
Water emission	S32616	Unspec.-N	3,51E-02	g	0	0
Water emission	S32617	NO3-N	2,92E+00	g	0	0
Water emission	S32618	Tot-N	1,42E+02	g	0	0
Water emission	S32619	Na+ (natriumion)	1,44E+03	g		
Water emission	S32627	B (bor)	1,30E-01	g	0	0
Water emission	S32636	DOC	2,89E+00	g	0	0
Water emission	S32637	NH4-N	3,99E+00	g	0	0
Water emission	S32638	Mg (magnesium)	6,68E+00	g	0	0
Water emission	S32640	H+ (hydrogenioner)	1,70E+00	g	0	0
Water emission	S32641	Fosfat (PO4---)	1,85E-01	g	0	0
Water emission	S32642	Fluorid (F-)	6,99E-02	g	1	0
Water emission	S32643	AOX	5,94E+01	g	0	0
Water emission	S32644	COD	1,39E+04	g		
Water emission	S32645	BOD	3,06E+00	g	0	0
Water emission	S32656	Zn (zink)	1,27E+00	g	1	1
Water emission	S32658	water	8,78E+06	g		
Water emission	S32659	V (vanadium)	3,34E-03	g	1	1
Water emission	S32664	TOC	3,78E+01	g	0	0
Water emission	S32667	Unspec. sulphides	6,98E-04	g	0	0
Water emission	S32670	Se (selen)	3,34E-03	g	1	1
Water emission	S32673	Phenol	8,27E-02	g	0	1
Water emission	S32675	Pb (bly)	5,56E-02	g	1	1
Water emission	S32681	VOC	1,55E+00	g	0	0
Water emission	S32692	Unspec. iron oxides	1,48E-01	g	0	0
Water emission	S32693	Ni (nikkel)	1,08E-01	g	1	1
Water emission	S32694	Ammoniak (NH3)	2,67E+00	g	0	0
Water emission	S32699	Mo (molybdæn)	3,34E-03	g	1	1
Water emission	S32706	2-propanol (isopropanol)	5,40E+02	g	1	1
Water emission	S32707	Hg (Kviksølv)	1,58E-03	g	1	1
Water emission	S32710	Hydrogencyanid (HCN)	5,04E-08	g	1	1
Water emission	S32711	Hydrogencarboner (HC)	1,22E+01	g	0	0
Water emission	S32716	Fe (jern)	6,66E+00	g	1	1
Water emission	S32718	Cu (kobber)	1,04E-01	g	1	1
Water emission	S32721	Chrom(VI)	2,31E-08	g	1	1
Water emission	S32722	Chrom(III)	6,25E-02	g	0	0
Water emission	S32727	Unspec. salt	1,37E+01	g	0	0
Water emission	S32731	Unspec. metals	3,70E+00	g	0	0
Water emission	S32733	Unspec. C9-C10 aromates	4,28E-04	g	0	0
Water emission	S32734	Unspec. organic compounds	1,21E+00	g	0	0
Water emission	S32735	Unspec. matter	8,58E-01	g	0	0
Water emission	S32737	Cd (cadmium)	1,33E-02	g	1	1
Water emission	S32738	Ca (calcium)	1,54E+02	g		
Water emission	S32741	Benzen	3,68E-04	g	1	1
Water emission	S32742	As (arsen)	1,31E-02	g	1	1
Water emission	S32745	Al (aluminium)	4,23E-02	g	1	1
Water emission	S32754	Unspec. heavy metals	1,31E-01	g	0	0
Water emission	S32756	Nitrogenoxider (NOx)	3,85E-07	g	1	0
Water emission	S32757	Hydrogenchlorid (HCl)	9,70E-03	g	0	0
Water emission	S32759	PAH	6,07E-02	g	0	0
Water emission	S32760	Cr (chrom)	1,53E-02	g	0	0
Water emission	S32764	Chlorid (Cl-)	2,54E+03	g		
Water emission	S32766	SS	9,09E+02	g		
Water emission	T32675	Pb	1,26E-13	kg	1	1
Water emission	TX-S-220	Tetradecan (mineral oil)	2,08E+01	g	1	1